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A STUDY OF STRATUS CLOUDS IN CENTRAL EUROPE

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Surface and rawinsonde observations from six locations in Central Europe were analyzed for the presence of stratus layers. Cloud height, depth, temperature, and stability were determined for each layer. Wind speed and shear associated with each layer were also determined. These data were recorded on magnetic tape and are summarized in detail elsewhere. This report documents → next page

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cont

Abstract Continued:

the procedures used to produce the tapes and the detailed analysis. It also provides a broad overview of the results of this analysis.

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A STUDY OF

STRATUS CLOUDS IN CENTRAL EUROPE

1.   INTRODUCTION

Stratus clouds present a significant hindrance to aerial operations in
Central Europe. The magnitude of this hindrance could be lessened, to some
degree, if 1) reliable cloud layer information were available to aid in
planning and/or 2) effective stratus clearing techniques could be instituted.
The work reported here provides some of the basic groundwork required for
either of these measures.

Rawinsonde observations from six stations in Germany were analyzed
for cloud layers by computer. For each layer detected, the following pa-
rameters were determined:
   1. pressure at the base
   2. pressure differential from top to bottom
   3. height of the base
   4. thickness
   5. temperature at top
   6. temperature at base
   7. minimum temperature
   8. mean stability
   9. mean wind
   10. wind shear
These data along with associated surface data were recorded on magnetic tape
for each observation. Temperature inversions were also detected, and these
data were included on the magnetic tape.

Surface observations were used to supplement the upper air data, and
to screen out those cases with too little cloudiness to be of interest or
with the wrong types of cloud. The surface data also allow the upper air

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analysis to be placed in proper context with respect to diurnal variations and the occurrence of cloudiness with the desired characteristics.

The primary products of this study are the magnetic tapes described above and a detailed computerized analysis of these tapes. This report documents the procedure used to produce the tapes and the detailed analysis. It also provides a broad overview of the results of this analysis.

2.   APPROACH

This section describes the rationale of the approach taken. A following section documents the details of the computer processing.

There are a number of limitations inherent in this sort of analysis which should be realized from the beginning. The primary limitations are 1) the accuracy of the rawinsonde instrument in determining whether it is in cloud, and 2) the fact that the observation is limited to one point in space and time.

Inaccuracies in the determination of an in-cloud condition arise from instrument errors in the humidity measurement and from the fact that clouds can occur at ice or water saturation. All observations used in this analysis were performed with the German rawinsonde instrument. This instrument uses a human hair hygristor and appears to provide data of high quality. Measurement errors were evident, however, and the method of handling them is discussed below. It is assumed in the analysis that the instrument is in cloud when either ice or water saturation is reached. In layers with humidities between ice and water saturation but with insufficient ice nuclei to induce formation of an ice cloud, this method would falsely indicate the presence of a cloud. From detailed inspection of samples of the data it appears that this case occurs infrequently, and that this error will not significantly affect the results.

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Since the rawinsonde samples only one point in the horizontal at each level in the atmosphere, a cloud layer with 50% coverage would have only a 50% probability of being detected. Since the situations of most interest here are those with the greatest cloud coverage, the error introduced is not nearly as serious as might be anticipated. Another potentially serious error stems from the fact that rawinsonde observations were seldom taken more frequently than two per day. This tends to bias the analysis to the times of day when the observations were taken. The effect of this on the results is discussed in a later section.

A preliminary screening of the upper air data was made using surface observations. All rawinsonde observations associated with total sky covers less than 50%, or which contained any observation of cumulus clouds (excluding cumulostratus) were eliminated. Even though stratus layers were associated, at times, with reports of cumulus clouds, it was felt that the cumuli probably dominated the atmosphere during those situations, making them inappropriate for this study. Cases with cloud covers less than 50% were eliminated because it was felt they do not pose a serious hindrance to the aerial operations of interest here, and basic limitations in the method do not allow such situations to be handled properly.

If a perfect relative humidity measurement were available for use, determination of the existence of a cloud layer would be a matter of comparing the measured relative humidity with water saturation at temperatures above 0°C and with ice saturation at temperatures below 0°C. Comparison of surface observations of cloud layers with the rawinsonde observations showed evidence of cloud penetrations in which the rawinsonde instruments recorded values as much as 5% relative humidity sub-saturated in winter months, and sometimes as much as 15% relative humidity below saturation values in summer months. A critical relative humidity value was defined as the saturation value (with respect to ice for temperatures colder than 0°C) minus a correction to compensate for the instrument error. The correction was allowed to take three values: 5, 10, and 15% relative humidity. Since the instrument correction was observed to vary primarily with season, it was decided to determine the appropriate value for each station for each

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month. So, a single value would be determined for Berlin for all Januaries. Another value would be assigned for all Februaries at Berlin. Each sounding was analyzed three times for cloud layers; once for each value of the instrument correction. The results were then compared to the surface observations to determine which of the instrument correction values was appropriate for a particular month at a particular station.

Performing this analysis by hand would be an enormous task, so a computer program was developed to provide an objective comparison of sounding-derived layer definition with surface observations. In order to reduce errors introduced by the sounding ascending through a hole in the cloud layer, the comparison was limited to observations which reported a coverage of 80% or greater for the cloud layer. Situations in which the first layer reported as 80% or greater was above another layer reported as more than 40% were not allowed in the comparison. It was felt that the surface observer could not reliably determine that a layer obscured by a lower layer of more than 40% coverage could be determined to have such complete coverage. Once the surface-observed layer to be used for comparison was determined, it was matched with the closest layer detected by the sounding analysis. The comparison was based on cloud base observations.

An exception to the above is that case in which the first cloud layer of 80% or greater coverage was found to have cloud layers of 40% or greater coverage within 300 meters below its base. In this case, the best match that could be obtained between the sounding-analyzed cloud layers and the surface-observed layers (the primary layer and those within 300 meters) was used for the comparison. This perturbation on the basic system was introduced to account for multiple layers reported in detail generally near the surface. Such layers often connect with each other in various places, and it would be difficult to predict which layer the sounding would penetrate first.

From this procedure, we obtained a pair of cloud base measurements (one from the rawinsonde and one from the surface observation) for each observation time. The differences between these cloud base measurements were automatically summarized for the data sample (e.g., all Januaries at

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Berlin). Separate analyses were performed for each of the three instrument correction values, and these were compared to select the best value of the correction for that data sample.

The wind shear for each cloud layer was calculated as the vector difference between the wind at the top of the layer and the wind at the bottom of the layer. The wind at the bottom was subtracted from the wind at the top. The stability was calculated as the difference between the moist potential temperature at the top and bottom of the layer divided by the thickness of the layer. A positive value indicates stability; a negative value indicates instability. Derivation of the other parameters is obvious from their description.

Only cloud layers with bases below 5,000 meters AGL were considered in this analysis. Clouds above this level would not significantly hinder the aerial operations of interest here.

No attempt was made to utilize soundings with missing data. The time and funds required to recover information from such observations is not warranted by the amount of data which would be recovered. We found only a few percent of the observations which were eliminated because of missing data. It should be noted that the manipulations to account for problems in the data format, as described in Section 3, are not an attempt to recover missing data.

3.   DATA

The data used in this analysis were obtained from the National Climatic Center, Asheville, North Carolina. All of the data were provided on magnetic tape to facilitate computerized analysis.

Table 1 lists the data used, and Figure 1 shows the location of the observations. Surface and upper air observations were made at the same point for all stations except Idar-Oberstein. Since surface data were not available at Idar-Oberstein, data for Wiesbaden (about 80 km away) were used.

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Figure 1. Location of stations used in analysis. Stars indicate location of rawinsonde stations. All stations except Idar-Oberstein also performed surface observations. Surface observations from Wiesbaden (indicated by a circle) were used for the analysis of Idar-Oberstein.

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Table 1. Data used in analysis.

Location	Station Number		Period of Record	Length of Record
	Upper Air	Surface		
Berlin	10384	35104	Jan. 1963–Dec. 1970	8 yr.
Schleswig	10035	10035	Jan. 1960–Oct. 1971[a] (Jan. 1963–Oct. 1971)	11 yr., 10 mo. (8 yr., 10 mo.)
Essen	10410	10410	July 1965–Sept. 1970	5 yr., 3 mo.
Munich	10866	10866	Jan. 1962–Nov. 1969	8 yr., 11 mo.
Stuttgart	10739	34041	Jan. 1968–Dec. 1970	3 yr.
Idar-Oberstein[b]	10618	35010	Jan. 1968–Dec. 1971	4 yr.

[a]The surface analysis for this station used the 11 yr., 10 mo. period of record. However, the shorter period (8 yr., 10 mo.) was used in the upper air analysis in order to eliminate three early years in which the rawinsonde data rarely extended above 3,000 m.

[b]Surface data used for the analysis of Idar-Oberstein was from Wiesbaden, approximately 80 km away.

Rawinsondes for the first three years at Schleswig rarely exceeded 3,000 m and never exceeded 7,000 m. These years were deleted from the upper air analysis at this station to avoid biasing the results. The surface analysis included the entire period of records as indicated in Table 1.

All upper air data were provided in TDF 56 format. The format was consistent with its documentation except for the treatment of missing data. Different significant levels were apparently chosen for each parameter (temperature, relative humidity, wind, and height) in the original reduction. When converted to the TDF 56 format, frequently only the parameter demanding the level was reported, the other parameters being left blank. According to the documentation, blank entries indicate missing data. However, it was obvious, upon inspection of the data, that such an interpretation was erroneous.

To account for this factor in the processing, each sounding was inspected for missing data before further processing. Beginning at the surface, each level was checked for missing data (blanks). If all parameters (temperature, relative humidity, wind, and height) were missing, the level

was interpreted as truly missing data. If any one of these parameters were reported, an attempt was made to interpolate the others. Temperature, relative humidity, and height were interpolated in all cases where data were reported at levels above and below that being processed. Winds were interpolated in all cases where the levels of valid data above and below were separated by less than 3,000 m. Although this procedure may seem crude, the resulting treatment of reported missing data coincided with the professional judgment of the authors in nearly all cases checked.

All soundings containing missing data below 5,000 m were eliminated from the analysis to facilitate the processing. If erroneously reported missing data were not accounted for, nearly all soundings would have been eliminated. After accounting for these format discrepancies, only a few percent of the soundings were dropped from the analysis for missing data.

Surface data from Berlin, Stuttgart, and Wiesbaden were in TDF 14 format. The original data were hourly aviation observations. Not all of the observed parameters were used. Only total sky cover, visibility, present weather, and cloud layer data were included in the analysis. These data were consistent with the format documentation with one exception. At Wiesbaden, all visibilities greater than six miles were apparently reported as 100 mi. Our analysis was unaffected since we were only interested in whether the visibility was less than one mile.

Surface data from Schleswig, Essen and Munich were in TDF 13 format. The original data were three-hourly synoptic observations. As in the case of the surface hourlies, only the total sky cover, visibility, present weather, and cloud layers were extracted from the data.

There are two kinds of cloud data reported in TDF 13 format: 1) a first group which gives amount, type, and height of low clouds but only the type of the middle and high clouds; and 2) four levels of supplemental cloud data, each giving amount, type, and height. It was decided to use the supplemental cloud data because they were more detailed and easier to correlate with the cloud data from TDF 14. When production runs were

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started, we found that an inordinate amount of data (51%, in one case) was being discarded because a non-zero total sky cover was reported without any cloud layers. An inspection of the raw data showed that the supplemental cloud data were not always reported. There seemed to be no consistent pattern to the observer's decision whether to include the supplemental data. It was then decided to substitute the first cloud group for the supplemental data in those cases where a total cloud cover was reported but no supplemental cloud data were given.

The procedure was as follows: If one or more supplemental cloud layers were reported, the supplemental data alone was used. If there was a cloud group reported in the absence of the supplemental cloud data, it was translated into the form of the supplemental cloud layers. The reporting of the cloud group consists of the amount, type, and height of the low cloud, and the types of the middle and the high clouds. If all three elements for the low clouds were given, these were used as the first layer. The types of the middle and high clouds, if present, were used as the types of the second and third layers, with no amounts or heights. If the amount and height of the low cloud were given with no type, this was taken to mean that there was no low cloud and the amount and height of the report referred to the middle cloud. In this case, the first layer would use the middle cloud type as the type of the first layer, and the type of the high cloud as the type of the second layer.

The type codes of the supplemental clouds are less detailed than the low, middle, and high type codes. Table 2 shows the scheme used to condense the cloud group data into the code for the supplemental cloud data.

4. METHOD

The approach to the data processing was based on two concepts our experience has shown to support cost effective processing of large data sets. First, the data processing should be divided into small tasks which are more easily programmed. Second, a "master file" containing all derived parameters should be produced. By working with small portions of the programming effort, debugging is made much more efficient. Intermediate outputs

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Table 2. Translation of cloud type codes.

Supplemental Cloud Data		Cloud Group Data	
Code	Description	Code	Description
			High Clouds
0	Cirrus	1,2,3,4	Cirrus
1	Cirrocumulus	9	Cirrocumulus
2	Cirrostratus	5,6,7,8	Cirrostratus
			Middle Clouds
3	Altocumulus	3,4,5,6,7,8,9	Altocumulus
4	Altostratus	1,2	Altostratus
5	Nimbostratus		(No Comparable Category)
			Low Clouds
6	Stratocumulus	4,5	Stratocumulus
7	Stratus	6,7	Stratus and Scud
8	Cumulus	1,2,8	Cumulus
9	Cumulonimbus	3,9	Cumulonimbus

are available at the end of each program so that errors may be detected before they propagate through the entire process. The most expensive part of processing large meteorological data sets is the derivation of the desired parameters (cloud base, stability, etc.) from the original data. Summarization of the parameters is inexpensive. By saving the derived parameters on a "master file", it is possible to generate a great variety of summarizations without regenerating the parameters each time.

Figure 2 shows the process flow chart. Data files are represented by standard magnetic tape symbols (a circle with a tail extending from its bottom to the right). Processing is indicated by a rectangle with the name of the program performing the processing. Merging processes are indicated by inverted triangles with the name of the program performing the merge operation. The process of collation is indicated by two triangles joined in the vertical at their vertices. This process appears several times and deserves explanation. When two files are collated (in the context of this study), any observation on the first file for which an observation of

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S1
XPAND 13/14
S2
CHECK
S3
CALL 13/14
S4 — DIFRQ 13/14

U1
CHECK
U2

COLLATE

S5   U3
CLRHRLY
S6

COLLATE

S7   U4
SNDANAL

U5' U5" U5'''

COLLATE
S8

MERGE SP   MERGE SP   MERGE SP

MF' VALID   MF" VALID   MF''' VALID
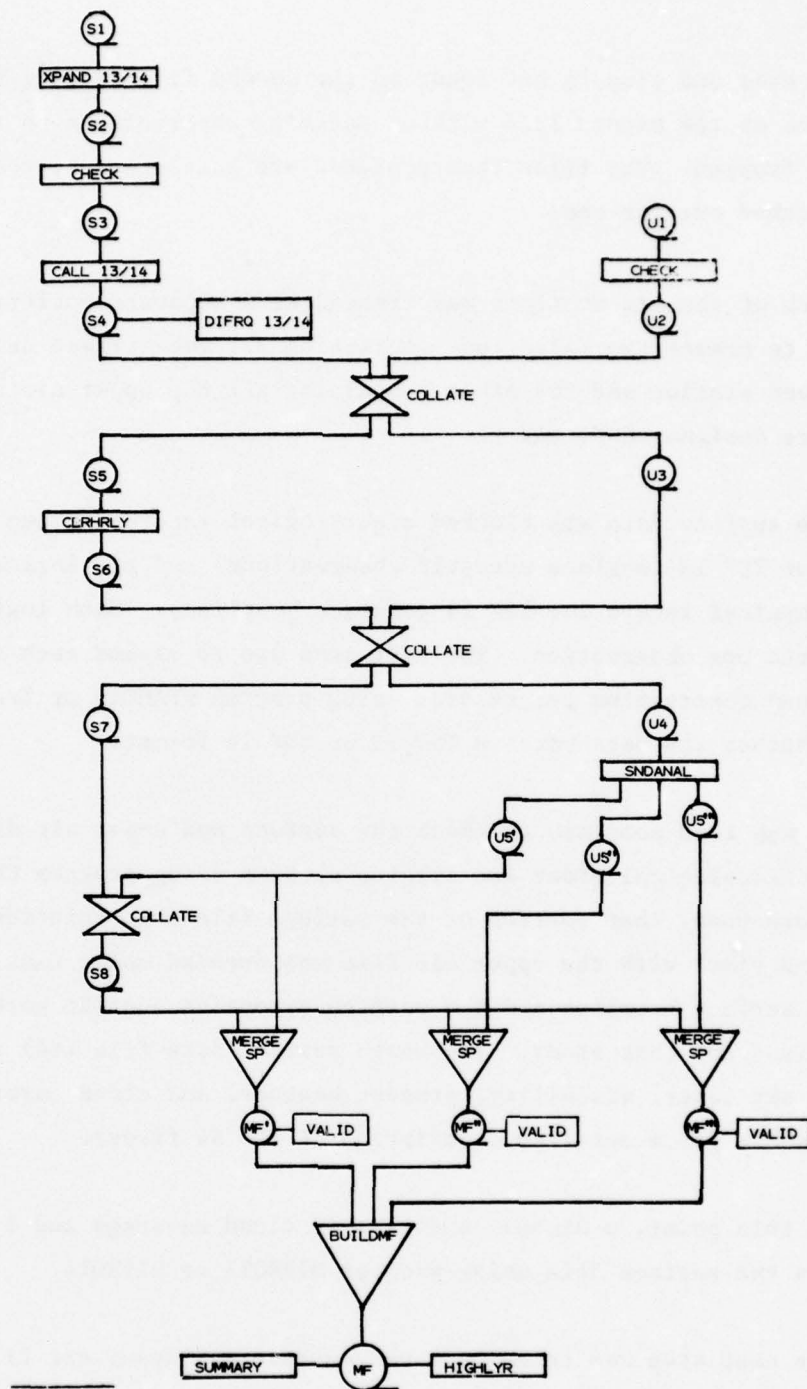
BUILDMF

SUMMARY — MF — HIGHLYR

Figure 2. Data processing flow chart. See text for explanation
of symbols.

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matching date and time is not found on the second file is eliminated. Observations on the second file without matching observations on the first file are also dropped. The files thus produced are guaranteed to contain observations matched one-for-one.

Each of the six stations was treated as a separate entity. The first step was to create two files, one containing all the surface data available for a given station and the other containing all the upper air data. These files were designated S1 and U1.

The surface data was blocked eight logical records to one physical record for TDF 13 (surface synoptic observations) and six logical records to one physical record for TDF 14 (surface hourlies). Each logical record constitutes one observation. The next step was to expand each surface data file to one observation per record, using program XPAND13 or XPAND14, depending on whether the data were in TDF 13 or TDF 14 format.

It was then possible to check the surface and upper air data for correct chronological order and station numbers using program CHECK. This having been done, that portion of the surface file that coincided in time (month and year) with the upper air file was decoded using CALL13 or CALL14. Both the surface hourlies and the surface synoptics contain more data than was required for this study. The basic surface data file (S4) contained only the sky cover, visibility, present weather, and cloud layer descriptions. (See Appendix for a detailed description of the S4 files).

At this point, a diurnal analysis of cloud coverage and type was performed on the surface data using program DIFRQ13 or DIFRQ14.

The next step was to collate the surface and upper air files on date/time, producing two matched files. Since this surface file was exactly matched with the upper air file, it was used to produce a frequency distribution of the times of the upper air soundings. This was performed by program CLRHRLY, discussed below.

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Next, clear observations (defined as those having less than 50% cloud cover), and observations including cumuloform clouds were excluded from the sample using program CLRHRLY.

Now, the surface file was collated again with the upper air file to produce an upper air file containing only those soundings matched to the cloudy, non-cumulus observations.

The upper air data were then decoded, corrected for format discrepancies, and analyzed using program SNDANAL. This program produced three separate files, each based on a different value of the assumed humidity instrument error (5, 10, and 15 percent relative humidity).

The base and top of each cloud layer were defined as the points at which the relative humidity equalled the critical value. The cloud layer itself was considered to be the depth over which the relative humidity equalled or exceeded the critical value. If the depth was zero, i.e., the relative humidity touched the critical value only once and then decreased, the layer was discarded. If the top of the layer was above the base by less than 10 meters, the top was arbitrarily raised to be 10 meters above the base.

Up to six cloud layers were defined for each sounding, but the maximum number analyzed was five. For each layer analyzed, the following parameters were computed: pressure at the base, depth of the layer in millibars, height of the base above ground level (AGL), thickness of the layer in meters, the temperature at the base, the temperature at the top, the minimum temperature within the layer, the mean stability of the layer, the mean wind direction and speed in the layer, and the wind shear from base to top.

Up to six inversions were defined for each sounding but the maximum number analyzed was five. For each inversion analyzed the following parameters were computed: pressure at the base, depth of the inversion in millibars, height of the base AGL, thickness in meters, temperature at the base, temperature at the top and mean stability within the inversion.

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Also recorded for each sounding were the surface temperature, number of cloud layers, number of inversions and highest level reached by the sounding.

One of the files produced by SNDANAL was then collated with the surface file to eliminate from the surface file observations for which the matching upper air observation had been deleted due to missing data.

Each of the upper air files was then merged with the surface data to produce three files with formats identical to the master file (See Appendix). Program VALID was then used to produce an automated comparison of surface observations with cloud layers analyzed by SNDANAL. The results were displayed by month and inspected manually to determine which instrument correction factor produced the most desirable results for each month of the year. Table 3 shows the values chosen.

Table 3. Relative humidity offset to account for instrument error. Entries are in percent relative humitity.

	Berlin	Schleswig	Essen	Idar-Oberstein	Stuttgart	Munich
January	5	5	5	5	5	5
February	5	5	5	5	5	5
March	5	5	5	5	5	5
April	10	5	5	10	5	5
May	10	10	5	10	10	5
June	10	10	5	10	10	10
July	10	10	5	15	10	10
August	10	10	5	10	10	10
September	10	10	10	5	10	10
October	10	10	5	10	10	5
November	10	5	5	5	10	5
December	5	5	5	10	5	5

Program BUILDMF then selected the appropriate months for each of the files MF', MF'', and MF''', and merged them to form the master file for the

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station. Program HIGHLYR was run to determine the height which each sound-
ing reached and the number of layers detected for each. Program SUMMARY
then displayed the results for categories of cloud base and depth by month
as shown in Figure 3. Parameters so displayed include:

1. frequency of occurrence
2. percent frequency of occurrence
3. mean wind speed and standard deviation
4. mean wind shear and standard deviation
5. frequency of cloud layers capped by inversions
6. percent frequency of cloud layers capped by inversions

The data sample was divided into warm and cold cloud layers. "Cold"
cloud layers are those which can be expected to be responsive to treatment
with glacogenic nuclei. All others are termed "warm". The criteria used
to identify clouds potentially responsive to such treatment was that the
minimum temperature in the layer be colder than or equal to $-3°C$.

5. VALIDATION

Figures 4 through 9 show the results of the automated comparison of
surface observations with the cloud layers inferred from rawinsonde ob-
servations. It is felt that these represent a conservative estimate of
the accuracy of the technique in defining the location of cloud base
(penetration of a cloud layer). Although no such comparison is available
for cloud top (exit from a cloud layer), detailed inspection of the rawin-
sonde data suggests the situation is reasonably similar to that at cloud
base.

In evaluating the method of detecting cloud layers, we must be aware
of the limitations of the surface observations and any cloud detection
technique which relies on rawinsonde data. Even though we require a report
of 80% coverage before accepting the surface observation of a cloud layer
for comparison, this means as much as 20% of the sky dome is visible to the
observer. Since the cloud decks have some finite thickness, the real
fraction of coverage in the horizontal planes is something less than 80%
depending on the cloud thickness and the observer's perspective. In the

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BERLIN (TEMPLEHOF AIRPORT)
DECEMBERS 1963-1970

SAMPLE BEFORE CLEAR AND CUMULUS OBSERVATIONS WERE EXCLUDED EQUALLED 274 CASES

MINIMUM LAYER TEMPERATURE LESS THAN OR EQUAL TO -3C
FREQUENCY OF OCCURRENCE (TOTAL SAMPLE EQUALS 214 OBS)

CLOUD BASE

CLOUD DEPTH	FOG VIS≤1 MI	BASE<1000 FT VIS>1 MI	BASE>1000 AND ≤5000 FT	BASE>5000 AND ≤15,000 FT	ALL BASE CATEGORIES
<500 FT	2	5	2	1	10
500-1000 FT	3	3	8	2	16
1000-3000 FT	1	8	16	4	29
3000-5000 FT	2	10	10	5	27
>5000 FT	2	19	14	2	37
ALL DEPTH CATEGORIES	10	45	50	14	119

Figure 3. Sample output from program SUMMARY. This output shows the frequencies with which cold cloud layers were detected in the various categories of cloud base and thickness during all Decembers at Berlin. Similar outputs were produced for all stations for each month.
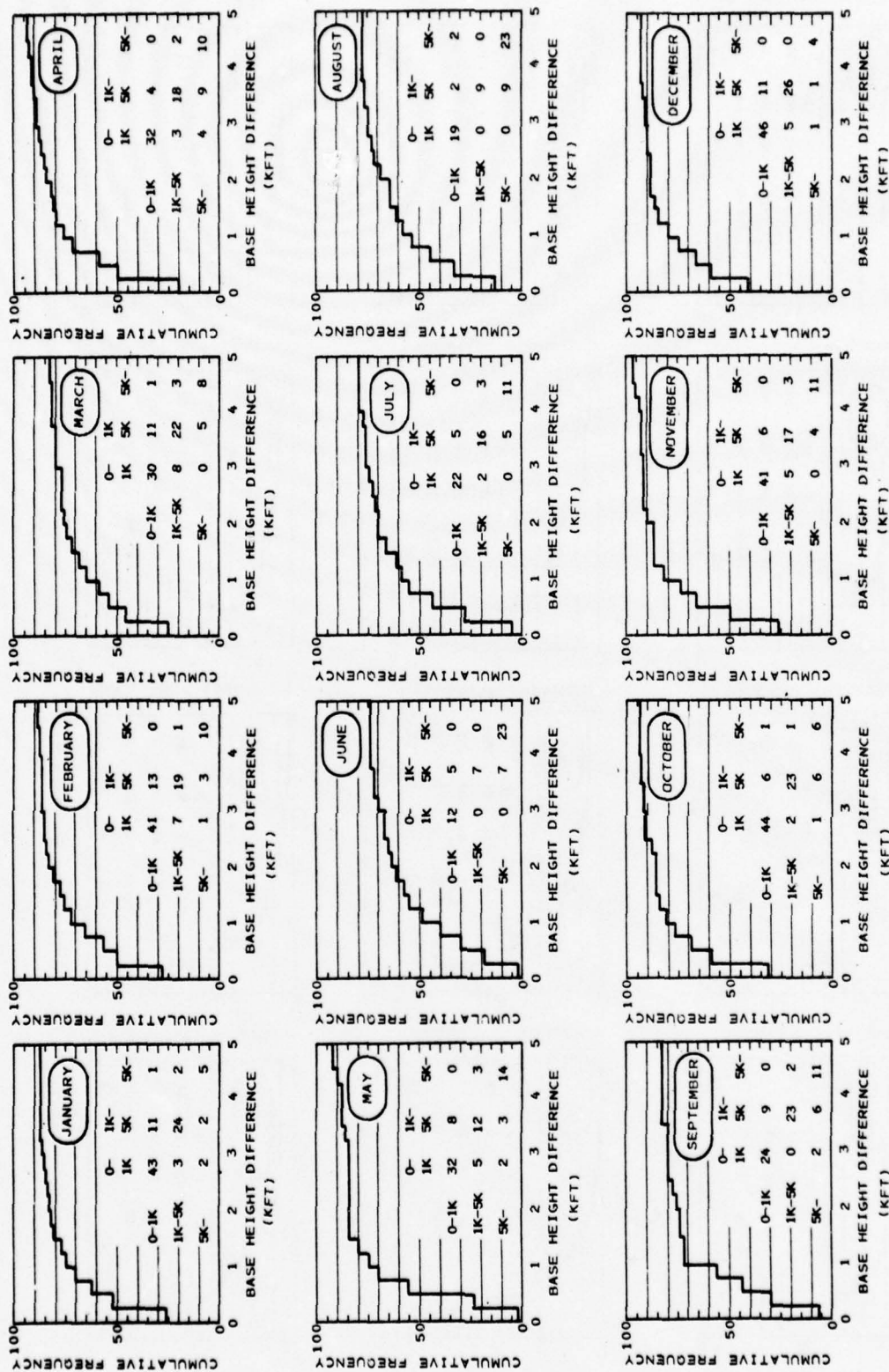
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Figure 4. Results of automated validation for Berlin. The abscissa is the absolute difference in kft between the surface and rawinsonde measurements of cloud base. The ordinate is the cumulative frequency of observations with differences less than the indicated value. The insert in the lower right hand corner of each graph compares the cloud base category determined from the sounding with that from the surface. Surface-determined categories are given across the top and sounding-determined categories on the left side.
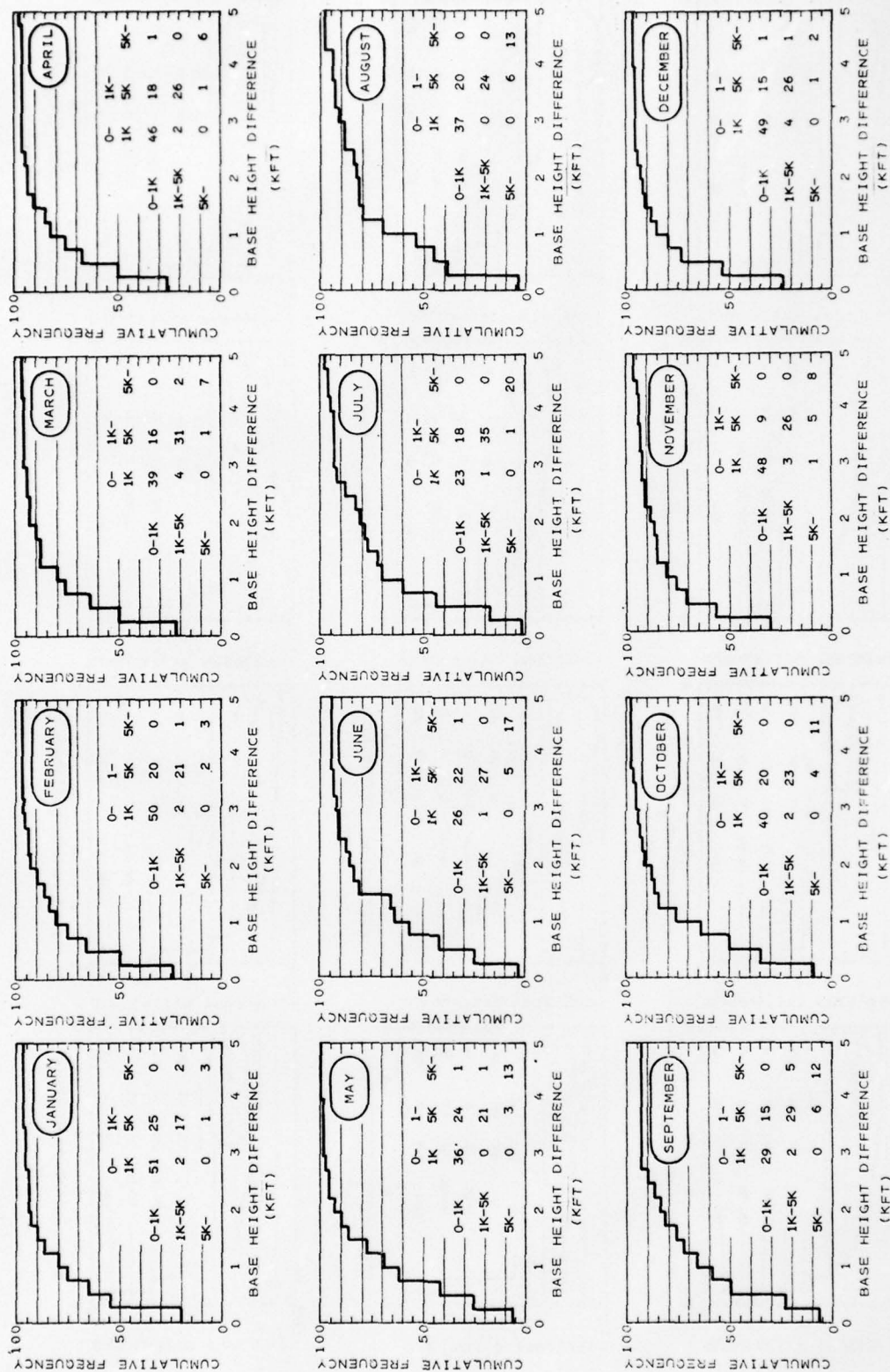
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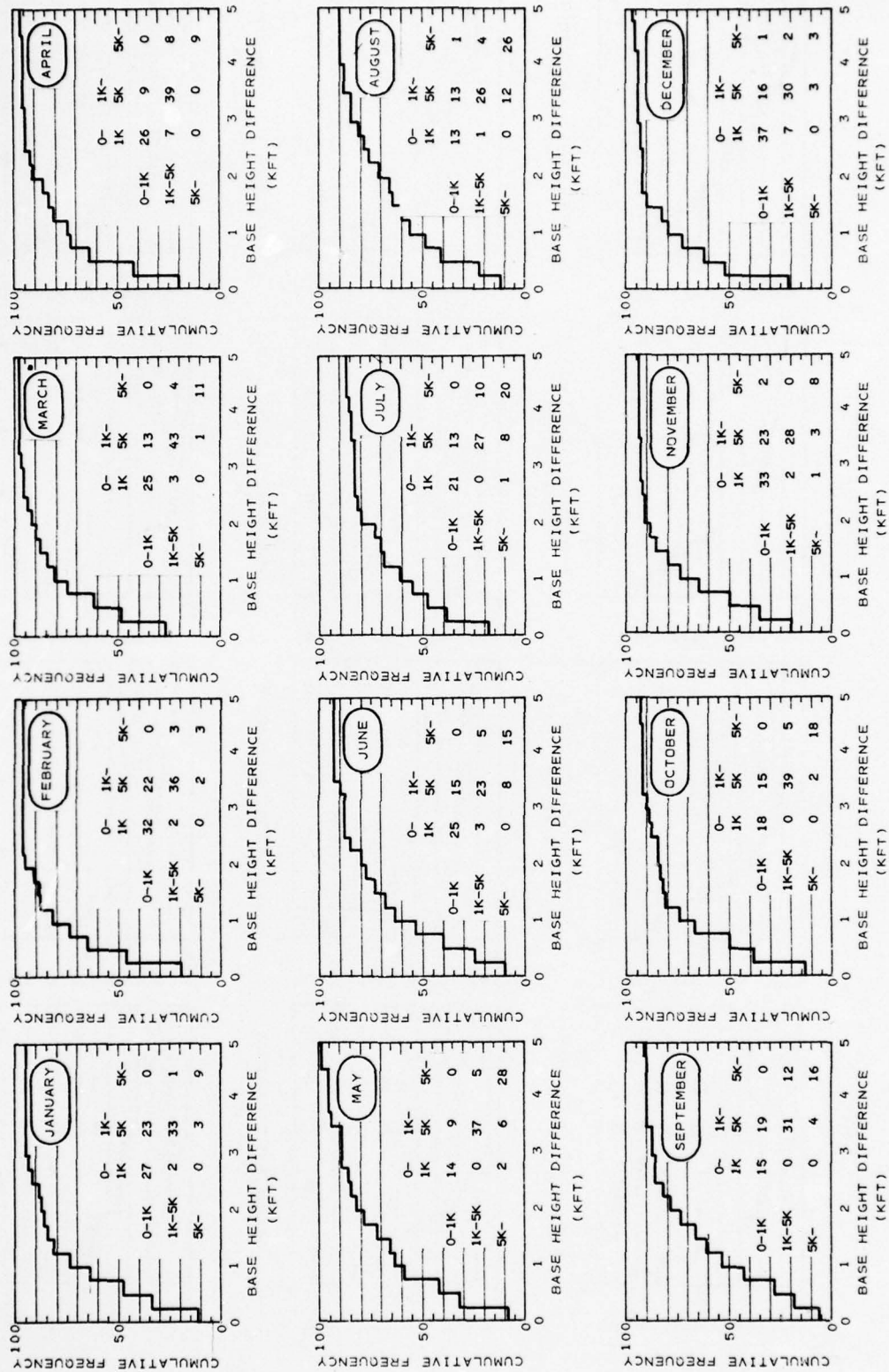Figure 5. Results of the automated validation for Schleswig.

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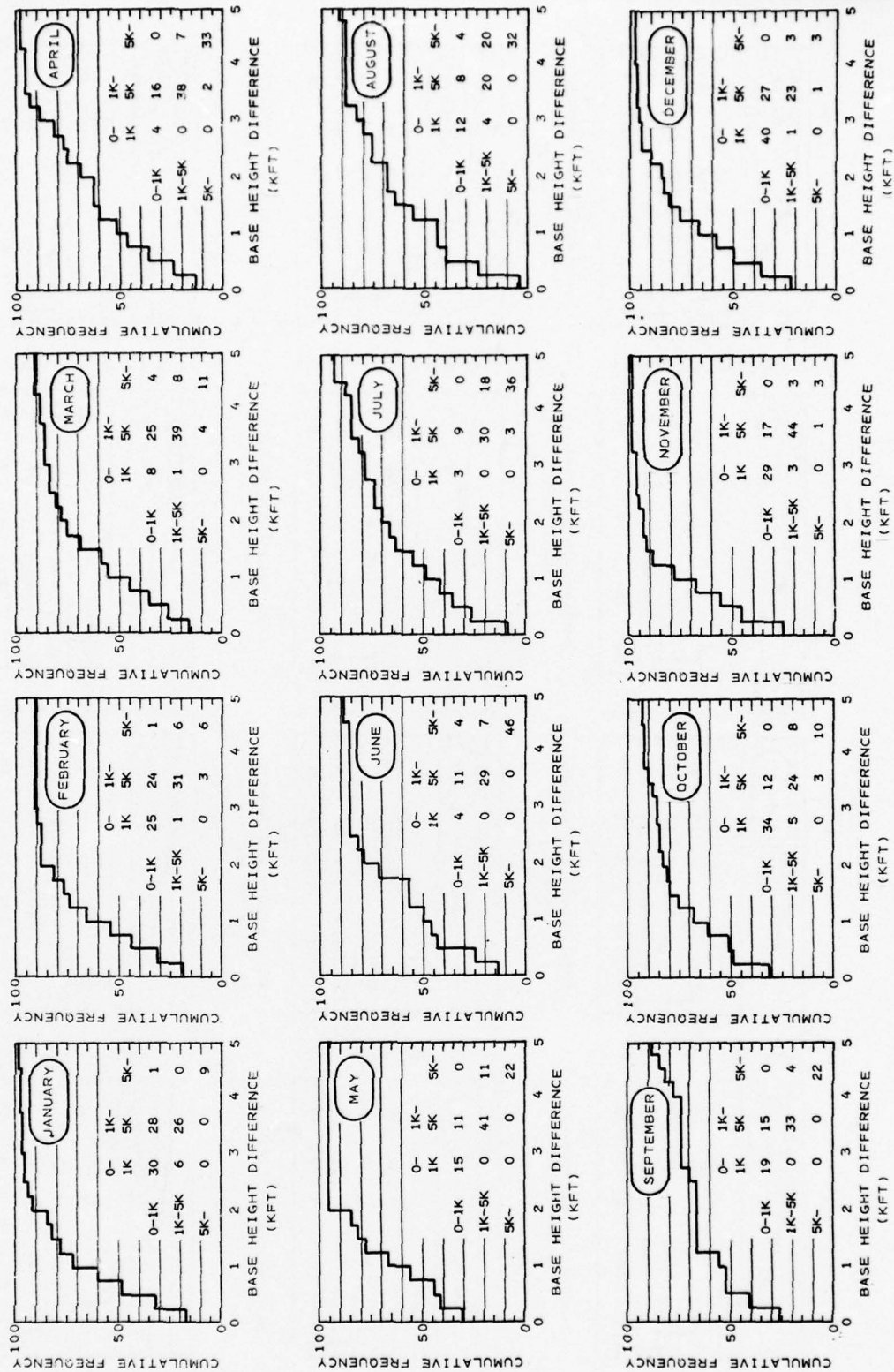Figure 6. Results of the automated validation for Essen.

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Figure 7. Results of the automated validation for Idar-Oberstein.
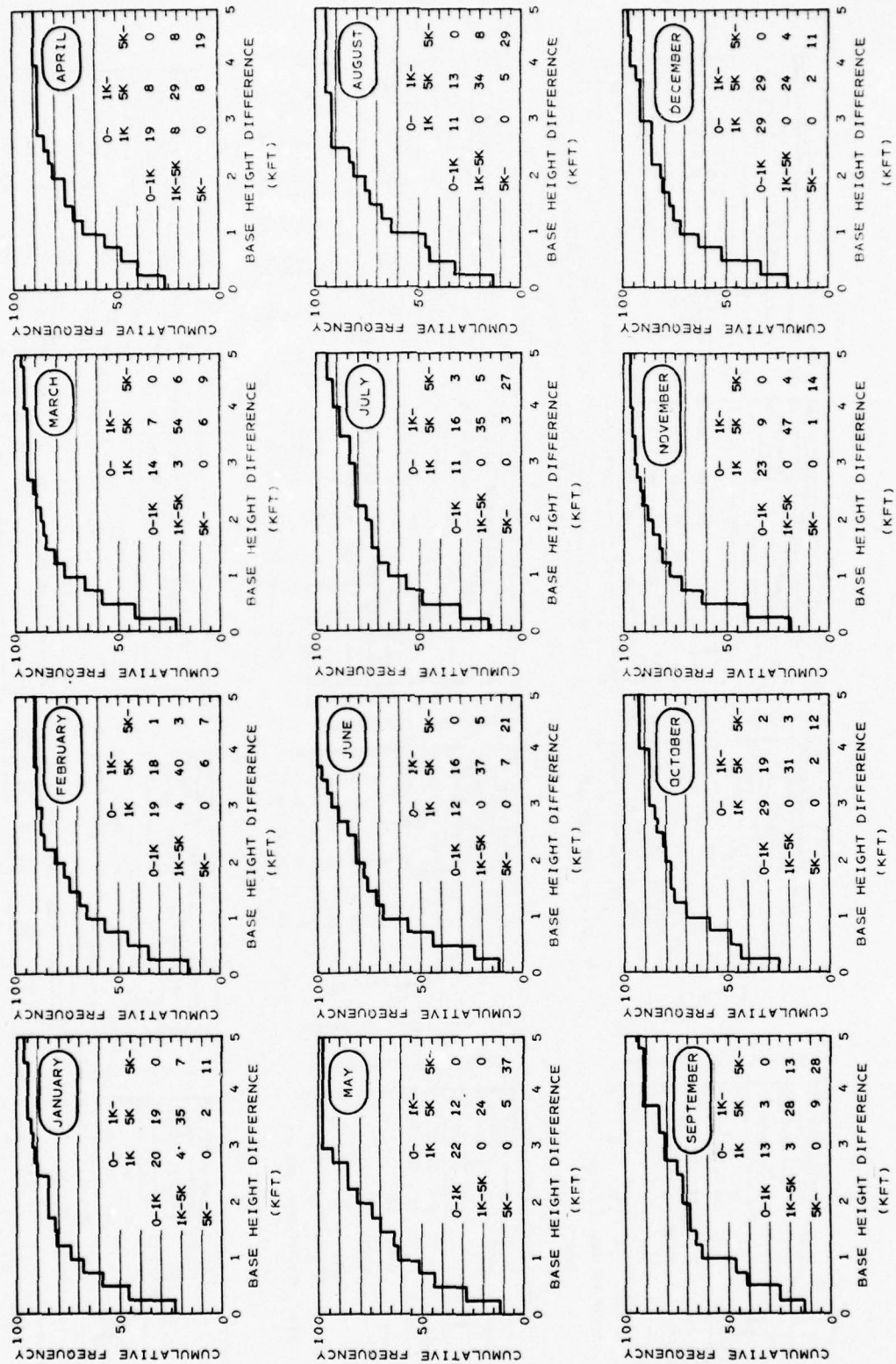
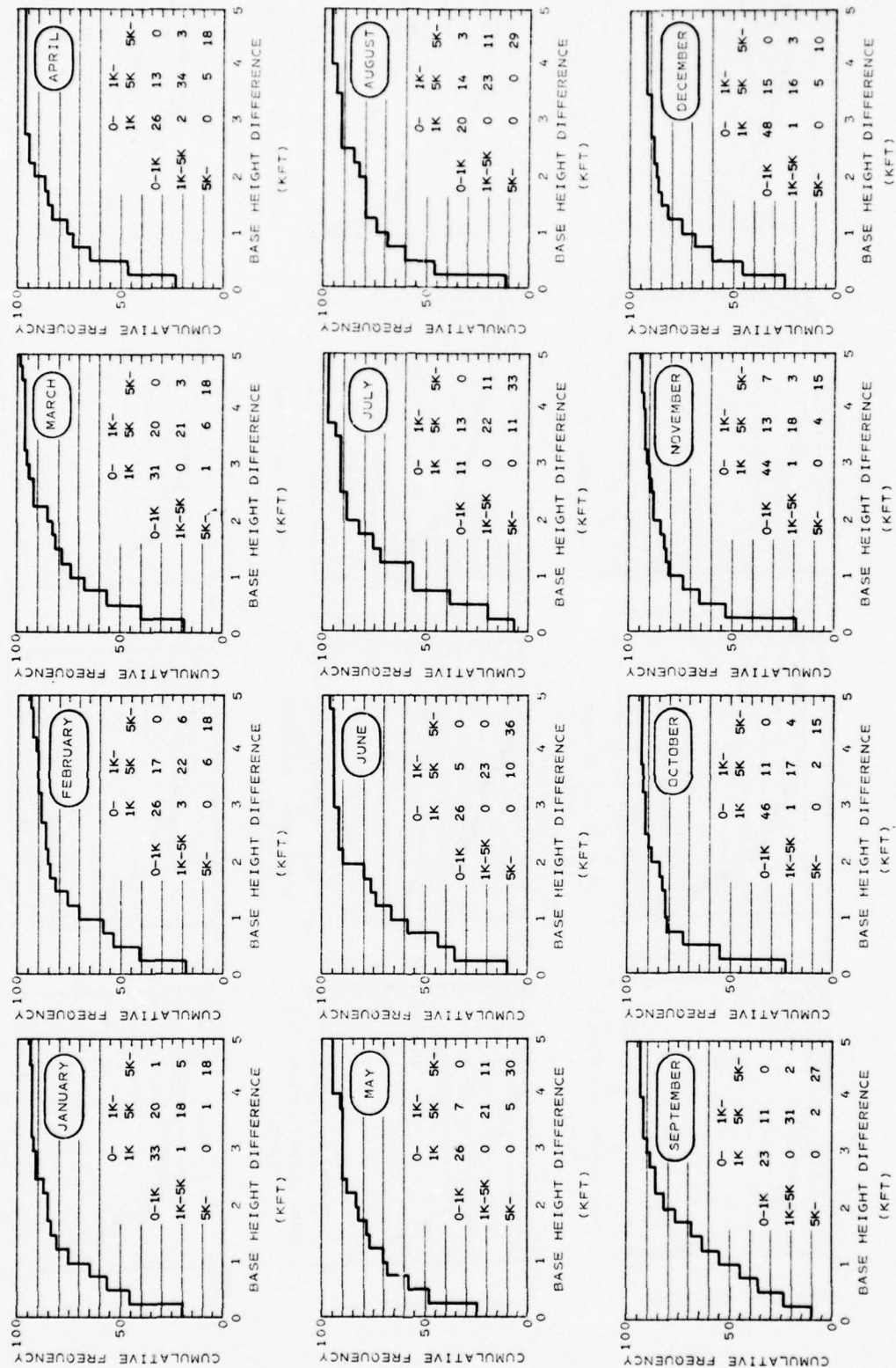Figure 8. Results of the automated validation for Stuttgart.

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Figure 9. Results of the automated validation for Munich.

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case of thick decks, the coverage could approach 50% in the horizontal plane and be reported as 80%. Such cases have been included in the analysis and will bias the results toward a poorer comparison.

In case of fog or precipitation, ceilings are often reported at up to several hundred feet above ground while the rawinsonde detects near satura- tion conditions from ground level. Such cases also score badly in the com- parison and are quite evident in the cloud base category comparison inserted in the lower right hand corner of each graph. Fairly large numbers of cases appear in the category of bases observed by the rawinsonde to be below 305 meters (1,000 ft) while the surface observation indicated 305-915 meters (1,000 - 3,000 ft). On inspection, these cases were found to be mainly observations which included fog or precipitation. The rawinsonde analysis probably produces the more appropriate results for purposes of this study, certainly in the case of fog.

Another factor conservatively biasing the comparison is that the surface observer's estimation of cloud base height is degraded for higher bases. In these cases, the rawinsonde provides a more accurate measure of height for clouds which it defines well.

The results of the comparison suggest the accuracy of the method varies seasonally, being most accurate in winter and least accurate in summer. A comparison within about 300 meters (1,000 ft) can be expected about 70% of the time in winter. Considering the conservative nature of the compari- son, the true accuracy of the technique may be considerably better than this. Based on detailed analysis of several cases, we feel the accuracy of the method is generally 90 to 150 meters (300 to 500 ft).

6. RESULTS

In this section we first present selected summarizations of the surface observations. This provides a background which then allows the results of the rawinsonde analysis to be presented in proper context.

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Figure 10 shows the seasonal variation of sky cover. The expected seasonal variation is evident at all stations with the greatest magnitude at Berlin. Overcast or nearly overcast conditions are prevalent about 60% of the time at Berlin in the winter, but only about 20% in the summer. All stations show a maximum of sky cover in December or January and a minimum in June or July.

Schleswig and Essen both show a similar pattern of frequent broken overcast conditions. This might reflect a coastal influence at these stations.

An October maximum of obscuring fog is indicated at all stations, except Wiesbaden. This effect is more prominent at the southerly stations of Stuttgart and Munich. There is also a general tendency for fog in fall and winter at inland stations with a less pronounced fluctuation at the stations under coastal influence (Schleswig and Essen).

Figure 11 shows the seasonal variation of cloud type. From this figure it is obvious that stratocumulus is the most prevalent type of cloud through-out central Europe. A similar pattern is observed at all stations except Stuttgart. To a certain extent, we may explain the difference at Stuttgart by its short period of record (three years). Its period of record is the smallest of all stations. However, Wiesbaden was evaluated for a four-year period of record and shows results consistent with the remaining four stations. It is unlikely that the addition of one year's data would account for such a difference. It would seem, rather, that there is a strong local perturbation of the large scale weather systems or that some discrepancies exist in the observing procedures at Stuttgart as compared to the other stations.

The typical pattern is one of stratus and stratocumulus clouds during the winter portion of the year, and stratocumulus and cumulus during the summer portion. The longest summer season occurs at the inland stations of Wiesbaden and Berlin, the longest winter stratus seasons occur at the coastal stations and at the inland station of Munich.

24
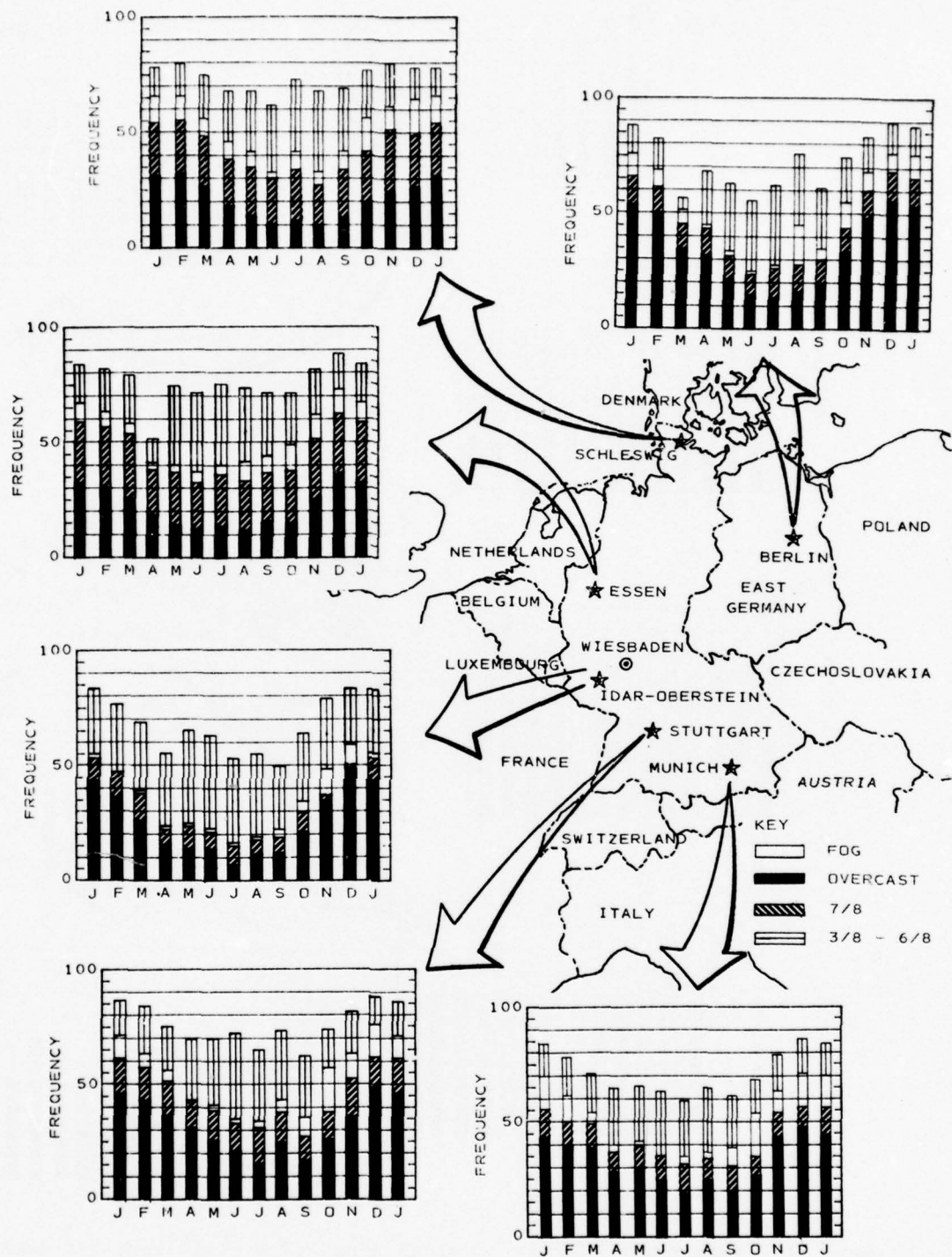
Figure 10.   Seasonal variation of sky cover.   The ordinate is the percent of all observations falling in the indicated categories.   The fog category includes only those cases in which the sky was obscured by fog.

25
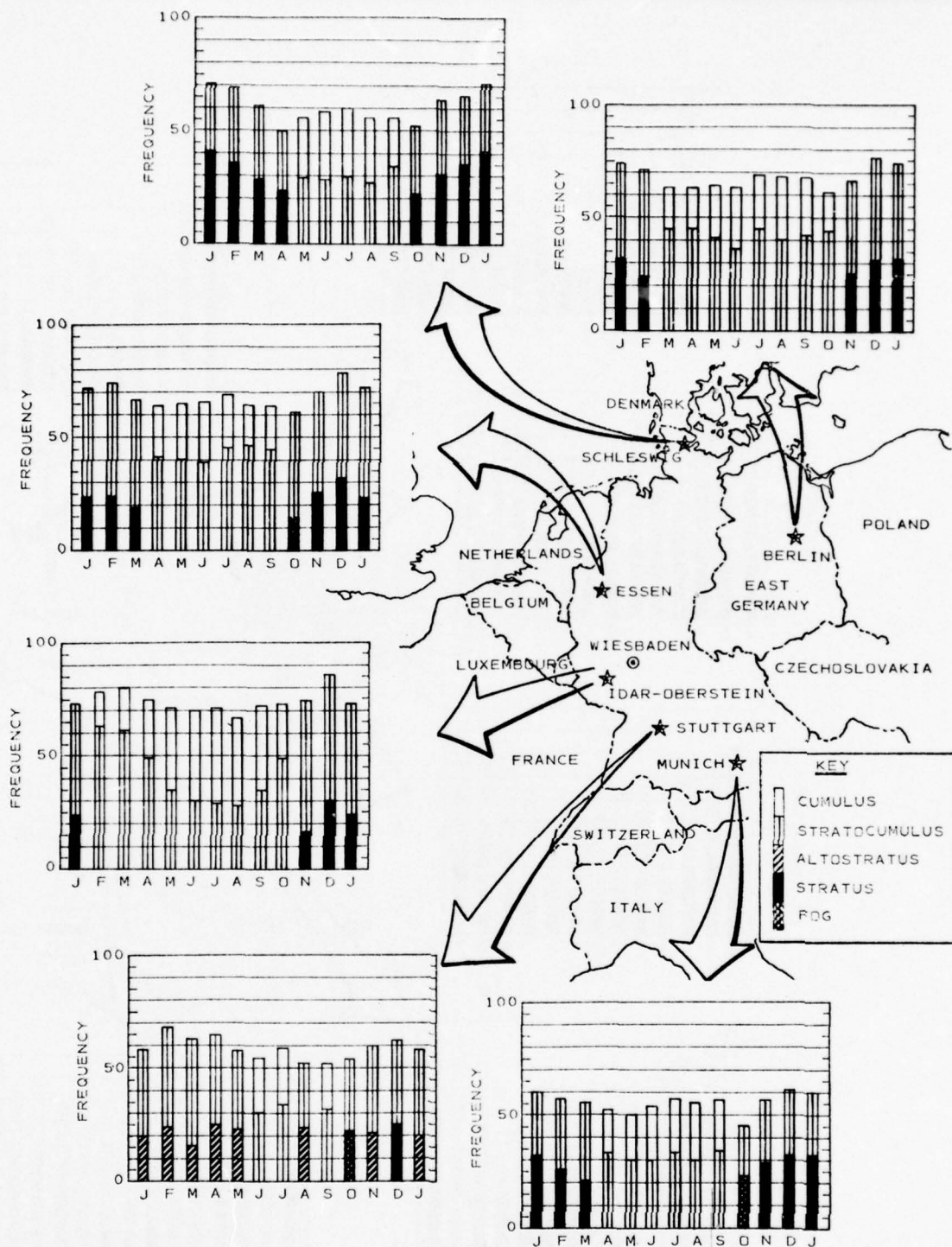
Figure 11. Seasonal variation of cloud type. The cloud type for each observation was the type of the cloud layer with the greatest coverage. Only the most frequent and second most frequent type are shown. The ordinate is the percent of all observations reporting cloud that were in the category. Here and throughout the report cumulus include all cumuliform clouds except cumulostratus.

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The prevalence of fog in the month of October is again evident at the two southerly stations of Stuttgart and Munich, and to a lesser degree, at Essen.

Figures 12 through 19 show the character of the diurnal variation in cloud cover for January, April, July, and October. These months were selected to represent each of the four seasons. The frequency of observation, hourly or 3-hourly, at the various stations is readily apparent from the graphs.

In January (Figures 12 and 13) we generally find maximum cloud cover in the early morning hours and minimums during the daytime. An exception is Stuttgart which possesses a double maximum with peaks near 03Z and 20Z. The variations are strongest at the inland stations and less pronounced near the coast. At Berlin and Stuttgart sharp decreases are apparent just after sunrise. At Stuttgart this is apparently associated with an increasingly convective nature of the clouds. There is also a hint that the midday minimum at Wiesbaden is associated with increased convectiveness. Strong variations are observed in the occurrence of fog (so thick it obscured the sky). The inland stations of Berlin, Stuttgart, Essen and Munich display this tendency for a daytime mimimum and a night time maximum. A smaller variation is evident at Schleswig, and Wiesbaden reports very little fog at any time.

April (Figures 14 and 15) shows the same tendencies for cloud cover, but less pronounced. All stations display midday convection with frequencies between 12Z and 15Z, and Wiesbaden also shows significant nocturnal cumuli peaking at about midnight.

Convection is the dominant feature in July (Figures 16 and 17) leading to more frequent conditions of clear to scattered sky cover. However, broken to overcast decks of stratocumulus are presented often enough at most stations to present a potential hindrance to aerial operations. Maximum frequencies of these conditions occur in the early morning. A strong diurnal tendency in convection is evident at all stations with the maximum

27

Figure 12.   Diurnal variation of sky cover in January.   The ordinate is the same
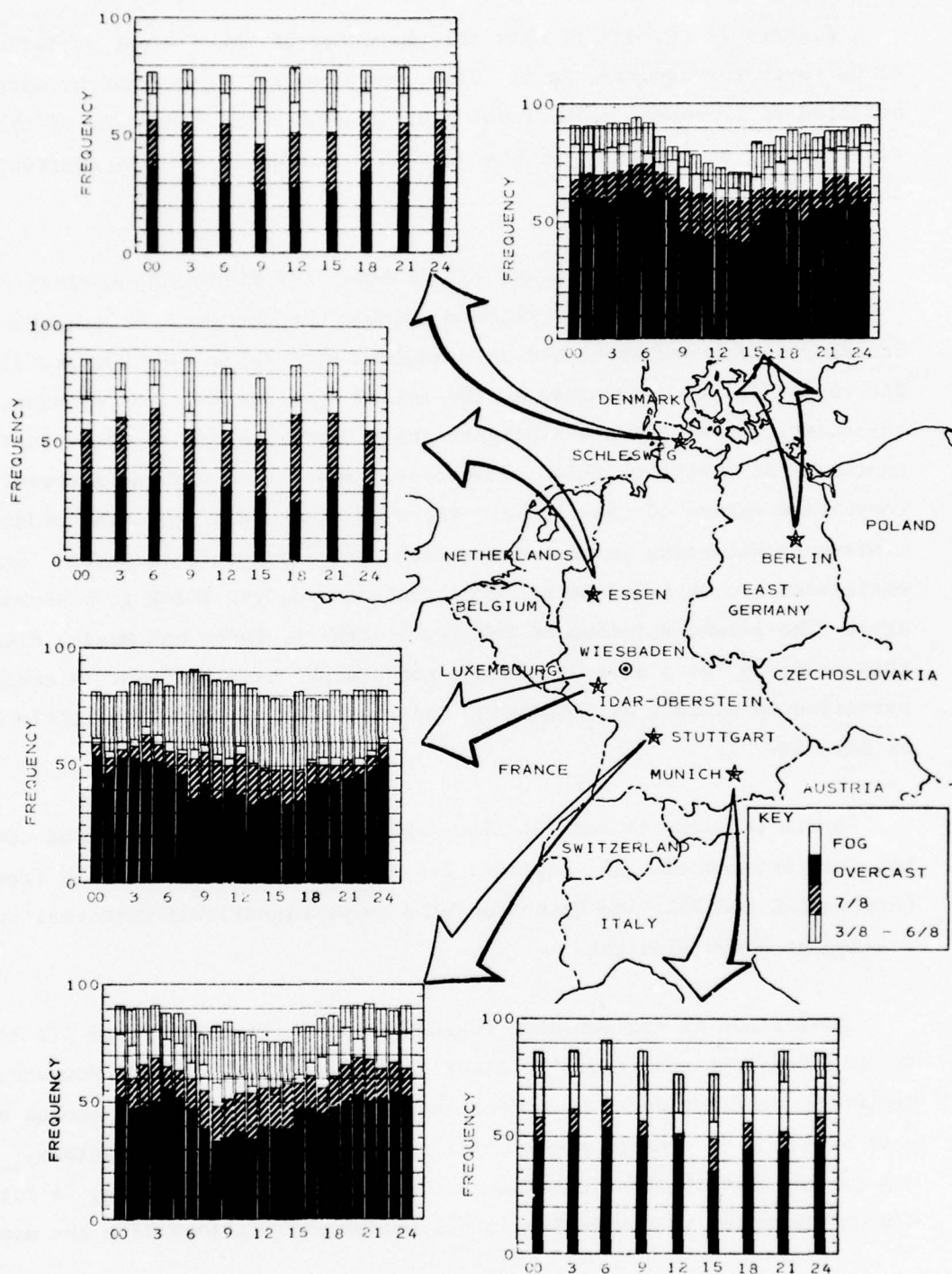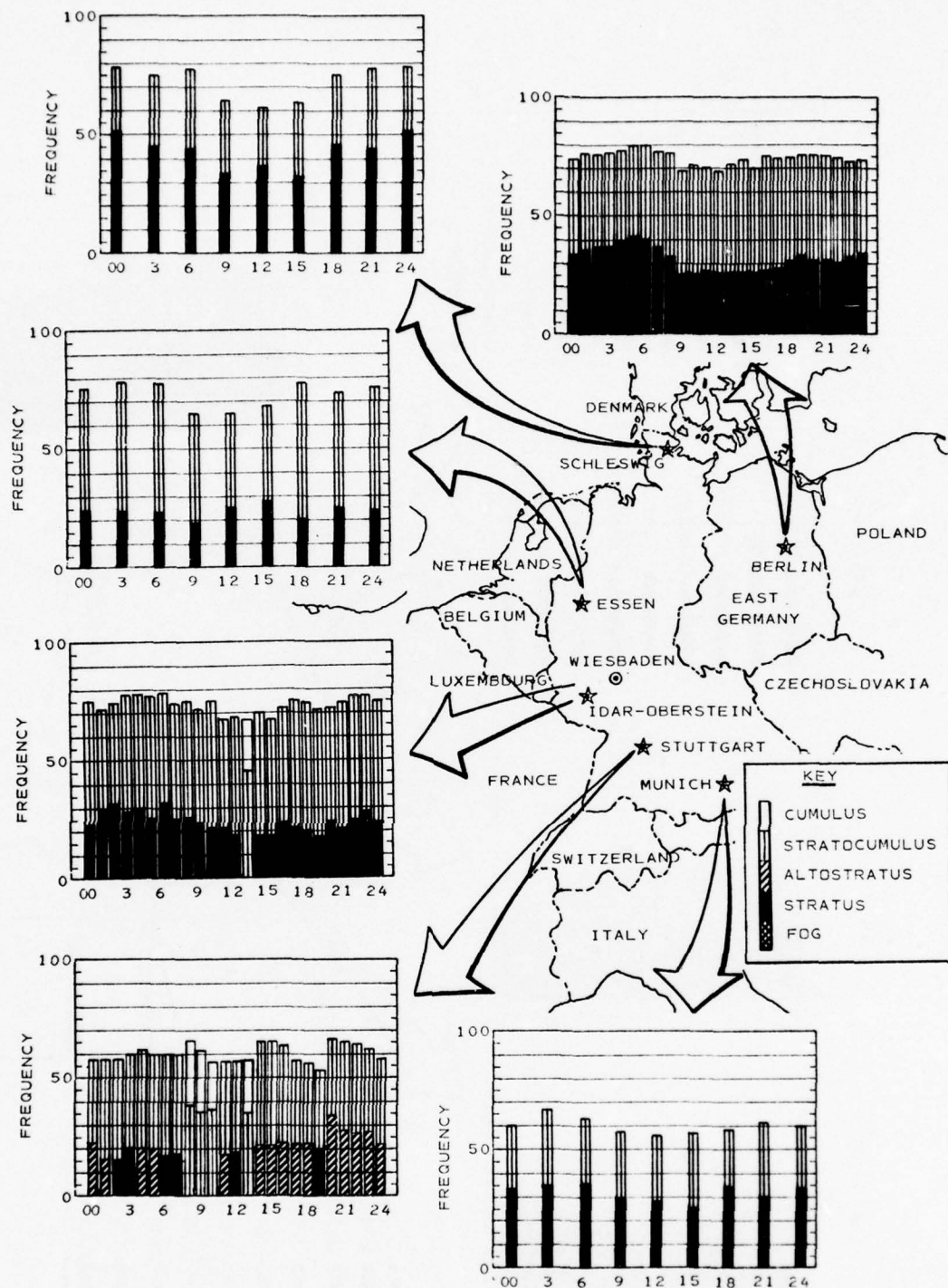as Figure 10.   The abscissa is Greenwich Mean Time.

Figure 13. Diurnal variation of cloud type in January. The ordinate is the same as Figure 11. The abscissa is Greenwich Mean Time.
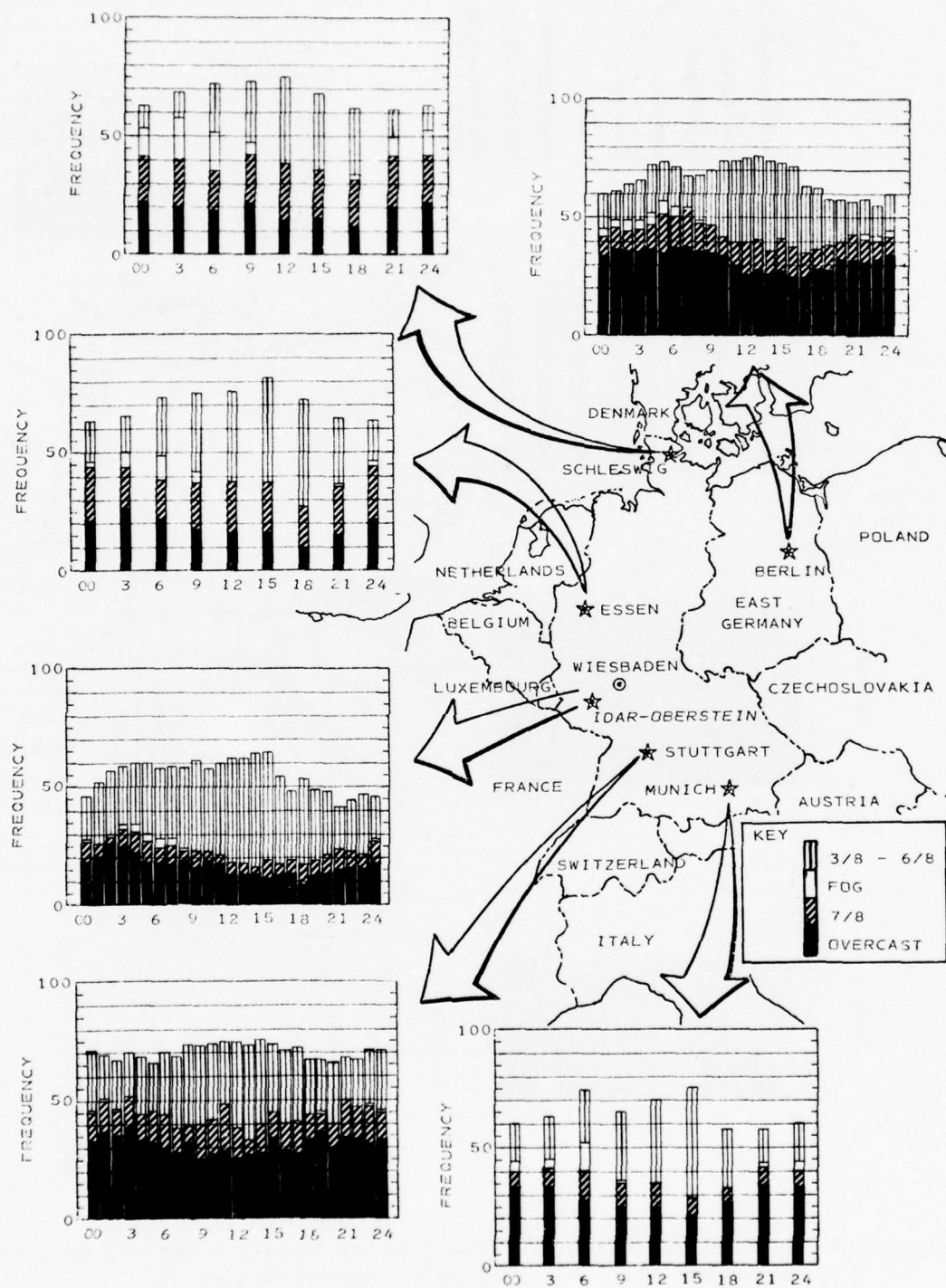
29

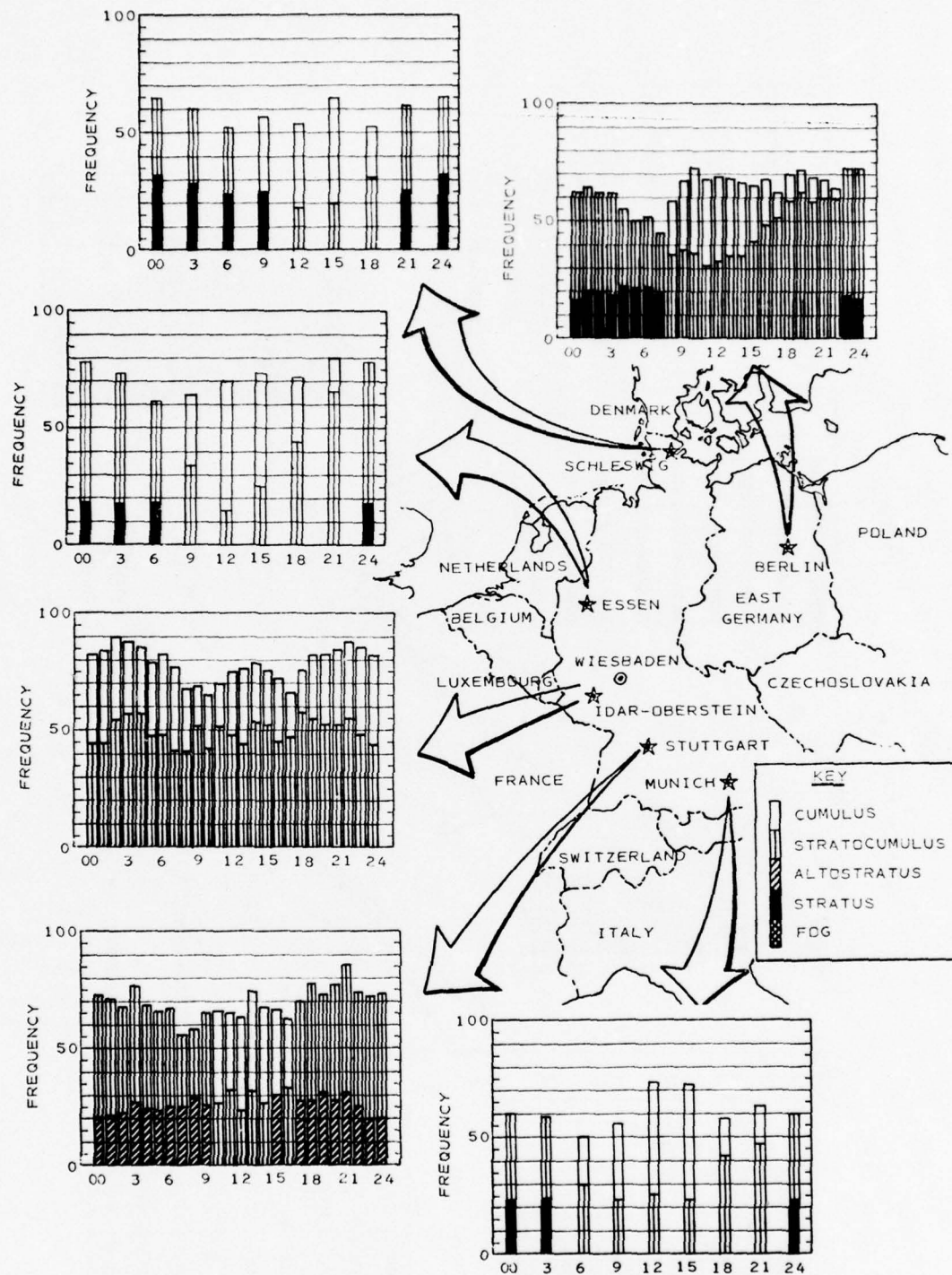Figure 14. Diurnal variation of sky cover in April.

30

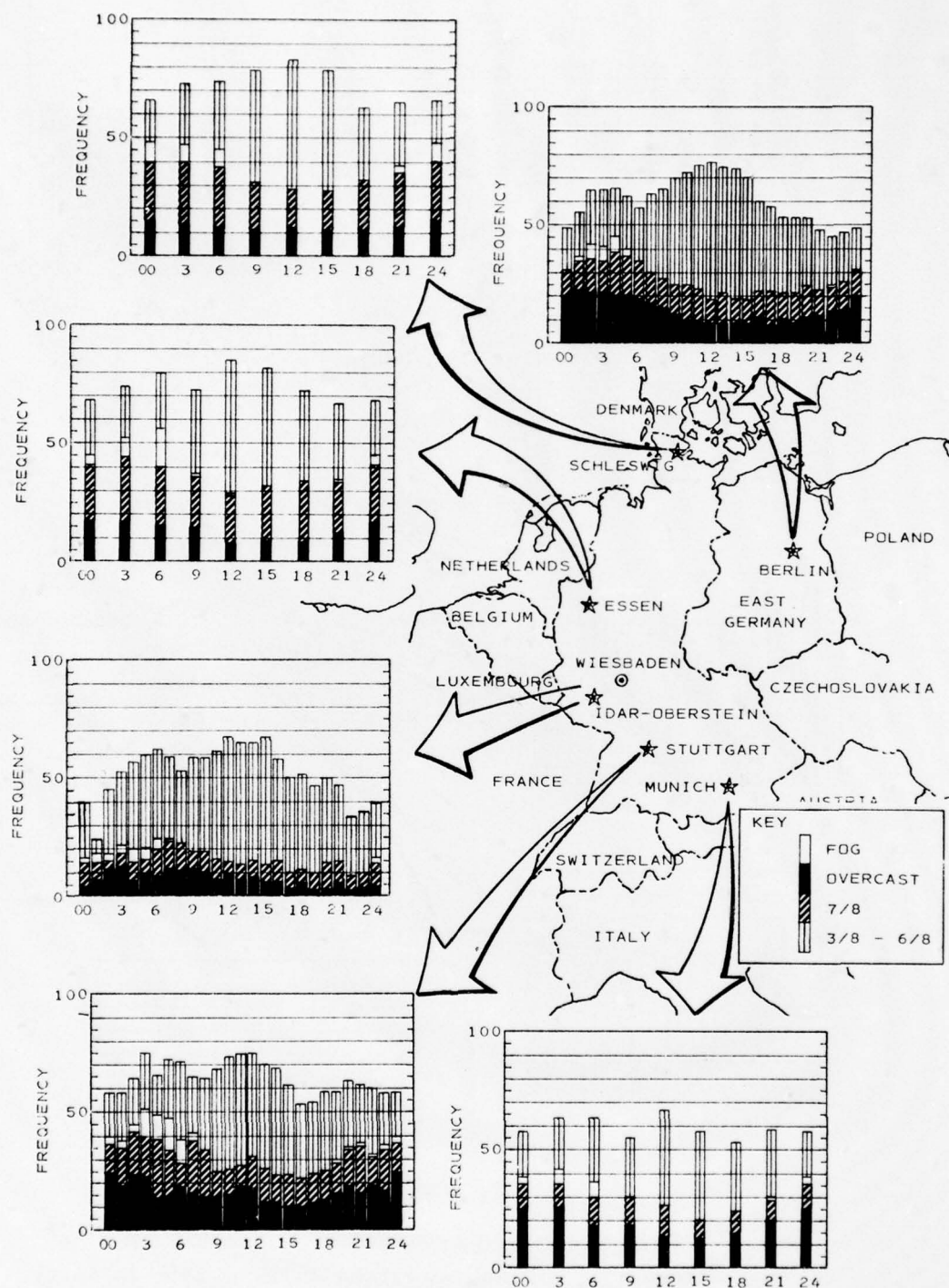Figure 15. Diurnal variation of cloud type in April.

31

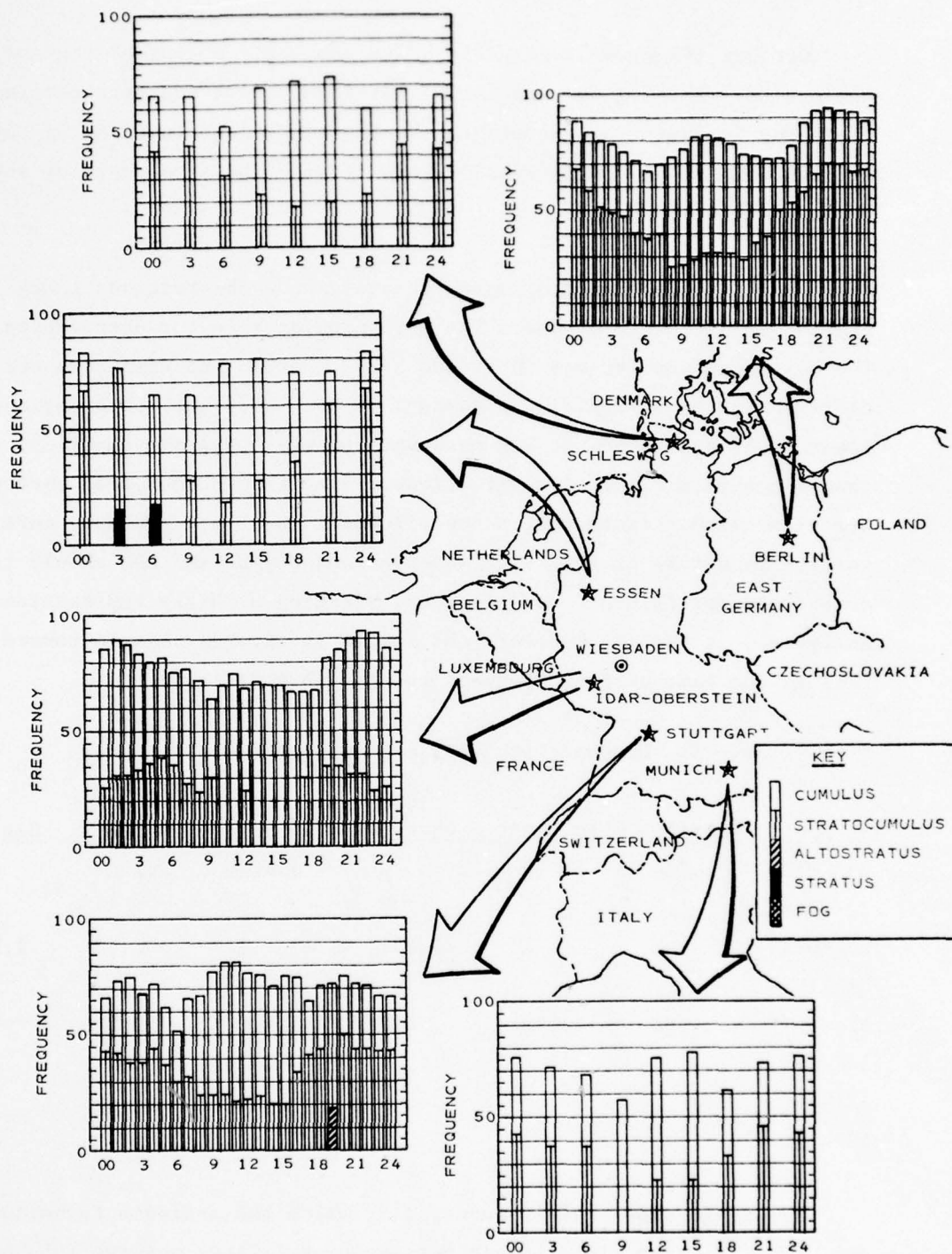Figure 16.   Diurnal variation of sky cover in July.

32

Figure 17. Diurnal variation of cloud type in July.

33

frequency near noon. The exception again is Wiesbaden which also shows frequent nocturnal convection.

October (Figures 18 and 19) is the month for nocturnal fog and daytime convection. The fog is especially prevalent at the southern stations. Wiesbaden is again the exception, showing significant amounts of convection throughout the day. Only small diurnal variations in amounts of sky cover occur in this month.

Table 4 indicates the number of rawinsonde observations taken at each station at each time of day. The most popular time for observation was 12Z. The next most popular was 00Z (0100 LST). Berlin and Wiesbaden are a bit different in that significant numbers of 06Z (0700 LST) observations were taken. The prevalence of 12Z observations will bias the upper air analysis toward the more convective situations. Even though "cumulus" observations are eliminated, stratocumulus are allowed. These are probably more convective in nature at 12Z. The observations at 00Z and 06Z should tend to compensate for this at most stations, yielding a fairly representative analysis. At Berlin, however, the sample is strongly biased toward 06Z. This is the time of most frequent stratus observations.

Table 4. Diurnal frequency of rawinsonde observations.

	Munich	Stuttgart	Idar-Oberstein	Essen	Schleswig	Berlin
23Z–01Z	1,736	1,079		1,824	2,275	9
02Z–04Z						41
05Z–07Z		1	1,031	1		2,520
08Z–10Z						313
11Z–13Z	2,698	1,088	862	1,820	2,962	757
14Z–16Z			2			3
17Z–19Z			5	1		
20Z–22Z						

Figure 20 shows the frequency with which the analysis technique detected one, two, or three cloud layers per sounding. Those observations not
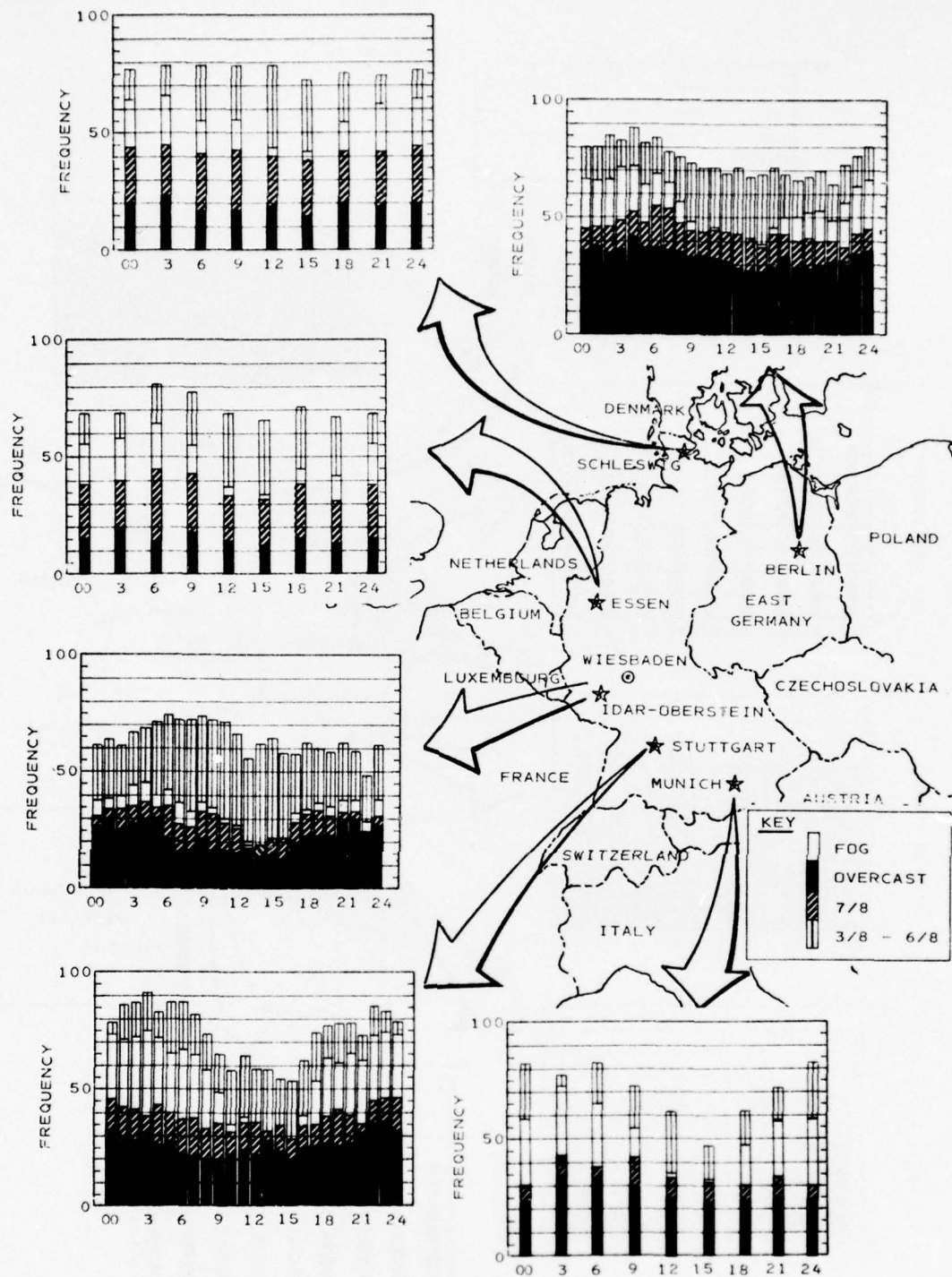
34

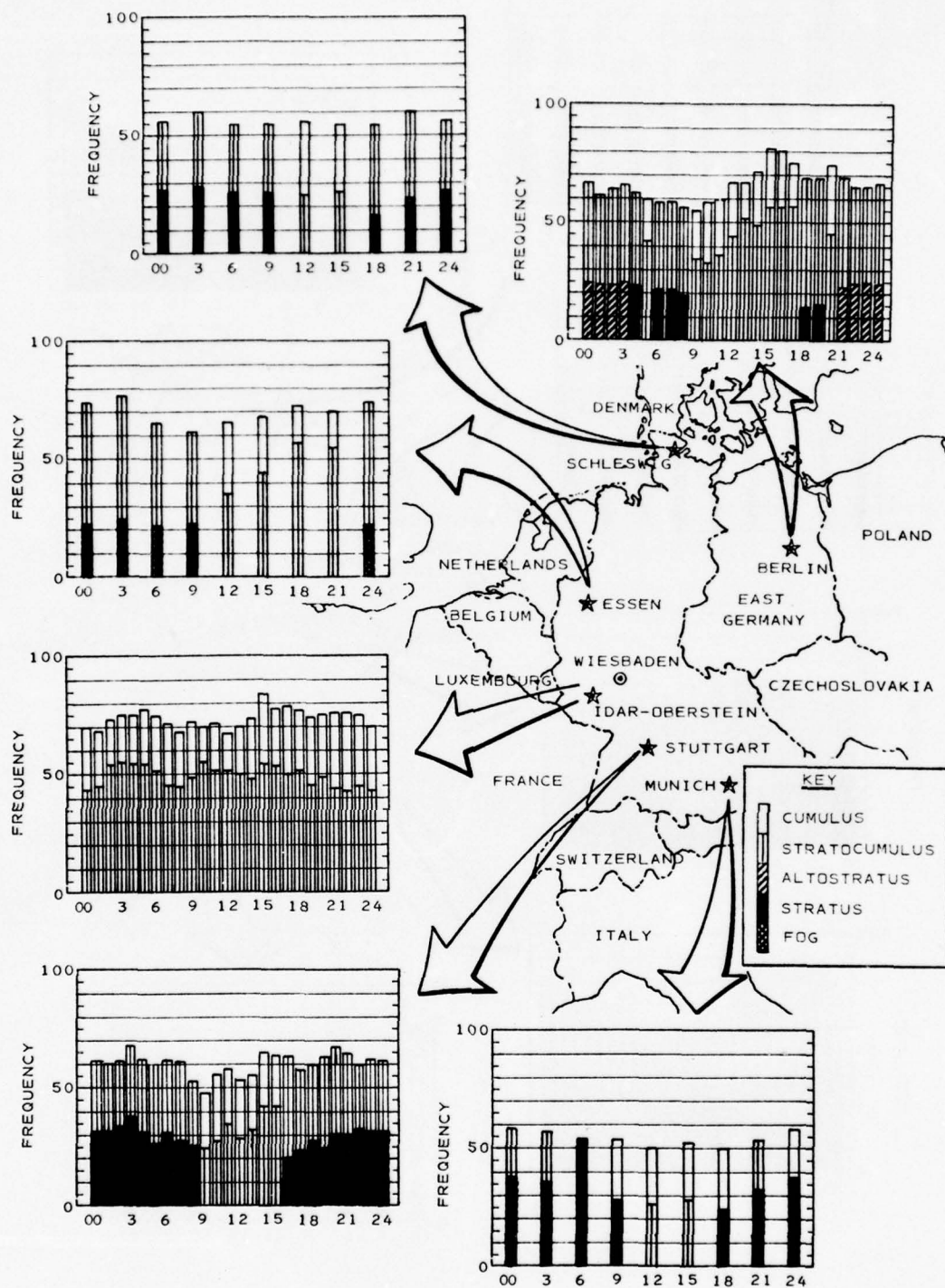Figure 18. Diurnal variation of sky cover in October.

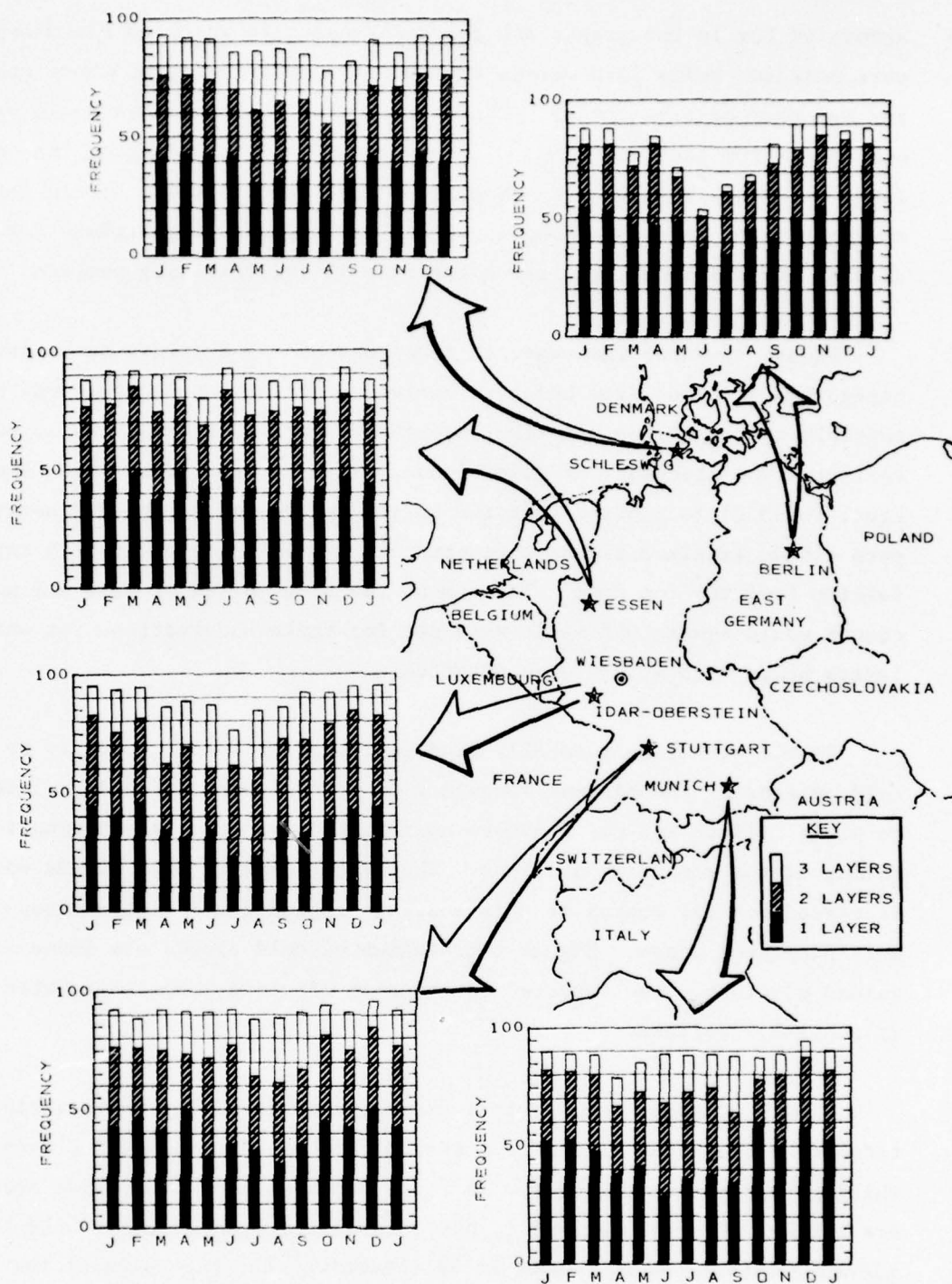Figure 19. Diurnal variation of cloud type in October.

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Figure 20. Frequency of multiple layers detected by rawinsonde.

accounted for in the graphs are generally cases in which no cloud layers were detected below 4575 meters (15,000 ft). Only a few of those unaccounted for had four or five layers. The remainder of this analysis deals only with one layer from each sounding. In the case of multiple layers, the lowest layer is used. This greatly simplifies the interpretation of the data and covers a major portion of the important situations. Suggestions for including the multiple-layer cases are made in the following section.

Figure 21 shows the seasonal frequency of cloud layers in various categories of cloud base height. Inclusion of the fog category was made possible by comparison with the associated surface observations as described earlier. The frequency of cold clouds (minimum temperature less than or equal to -3°C) is plotted from the bottom upward, while the frequency of warm clouds (minimum temperature greater than -3°C) is plotted in reverse fashion from the top down. The sum of the frequencies of warm and cold clouds would equal 100% if it were not for those observations for which no layers below 4575 meters were detected.

In the winter we generally find well over half the clouds to be in the cold category. The minimum frequency of cold clouds is found in late summer to early fall at the two southern-most stations and in late spring to early summer at the remaining stations. The frequencies of cold clouds would be increased for all months if this analysis included the higher clouds in the multiple-layer cases. Higher frequencies of cold clouds are found at the inland stations. The expected correlation of cloud temperature with height is generally evident.

Figure 22 shows the seasonal frequency of cloud layers in various categories of depth. There is a strong tendency for the cold clouds to be thicker than the warm clouds. In fact, about half of the clouds observed are thicker than the maximum (~ 800 meters) that conventional cold stratus clearing techniques are known to be effective on. Extension of the techniques to include thicker cloud layers would apparently be advantageous. The warm stratus decks seem to be much thinner, especially in the summer.
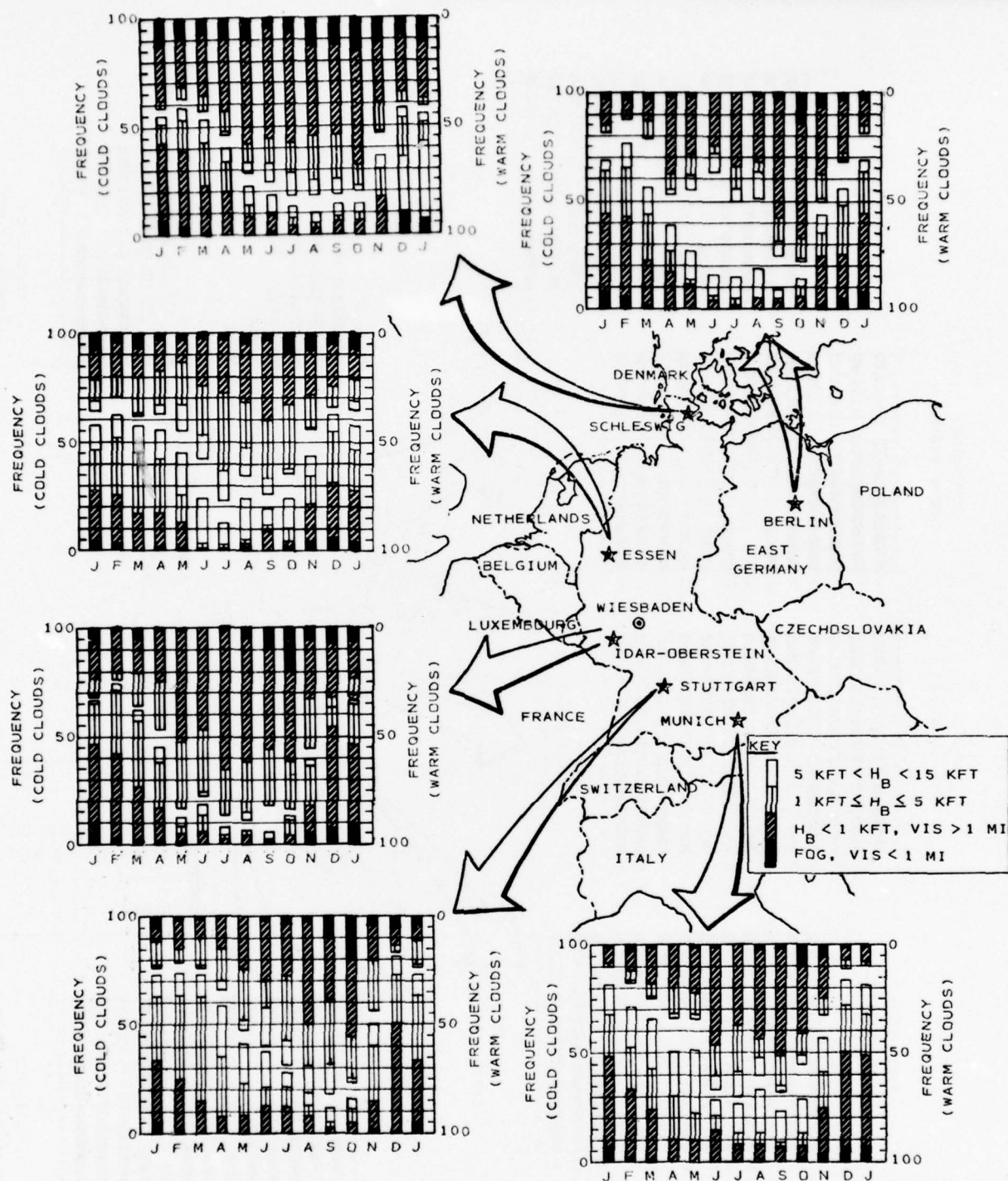
38

Figure 21.   Seasonal frequency of cloud layers by base categories.   See text
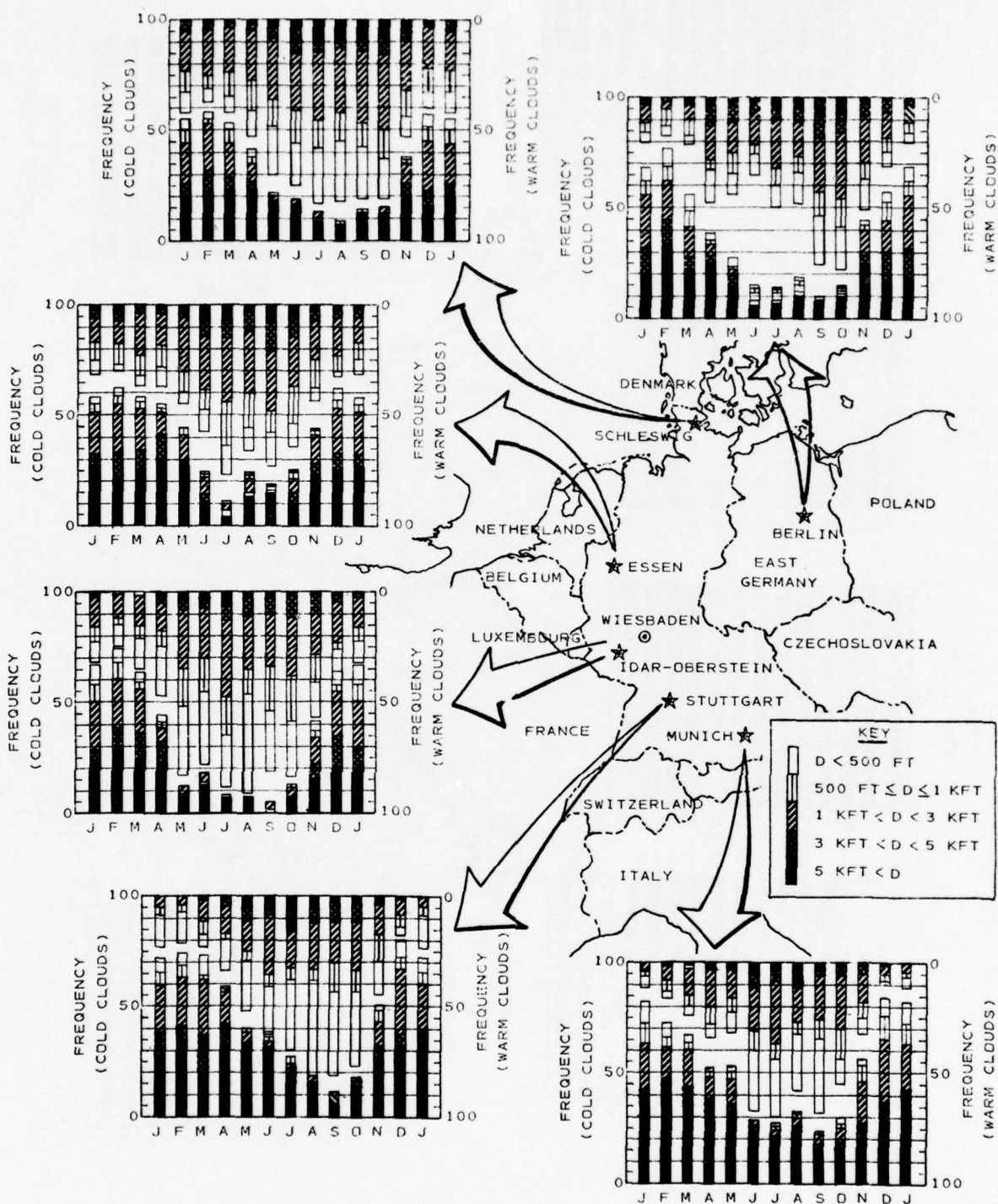for explanation.

Figure 22. Seasonal frequency of cloud layers by depth categories. See text for explanation.

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Figure 23 shows the percent of cloud layers which were found with inversions at cloud top. Some clearing techniques which may be applied to both warm and cold clouds (e.g., use of carbon black) are found to be most effective when the top of the layer is stable enough to prevent dilution of the seeding material into the air above the layer. We find that generally 40 to 60 percent of the warm cloud layers are capped by inversions with somewhat higher values at the southern stations of Munich and Stuttgart. The frequency of capping inversions is less for cold clouds in every case and is much more variable with time of year.

Figure 24 shows the seasonal variation of average wind speed for two selected categories of cloud base height. The expected tendency for higher speeds to be associated with higher clouds is observed. There also seems to be a general tendency for cold clouds to be associated with higher wind speeds. This statement cannot be made with a high degree of confidence, however, because many of the data samples used to derive the curves were too small to eliminate noise from the average.

Figure 25 displays a similar analysis for two selected categories of cloud depth. There appears to be little correlation between depth and wind speed; however, cold clouds again show a tendency to be associated with higher wind speeds. These statements must also carry the above disclaimer because of small sample sizes.

Figures 26 and 27 show similar analyses of average wind shear. Figure 26 indicates the expected tendency for high shears in the lower clouds. Cold clouds are associated with higher wind shears for a given height. Figure 27 shows that thicker cloud decks will possess higher wind shears. This is not surprising since we have defined wind shear to be the absolute vector difference of the winds at the top and bottom of deck. The tendency for colder clouds to possess higher shears is not present here.

41
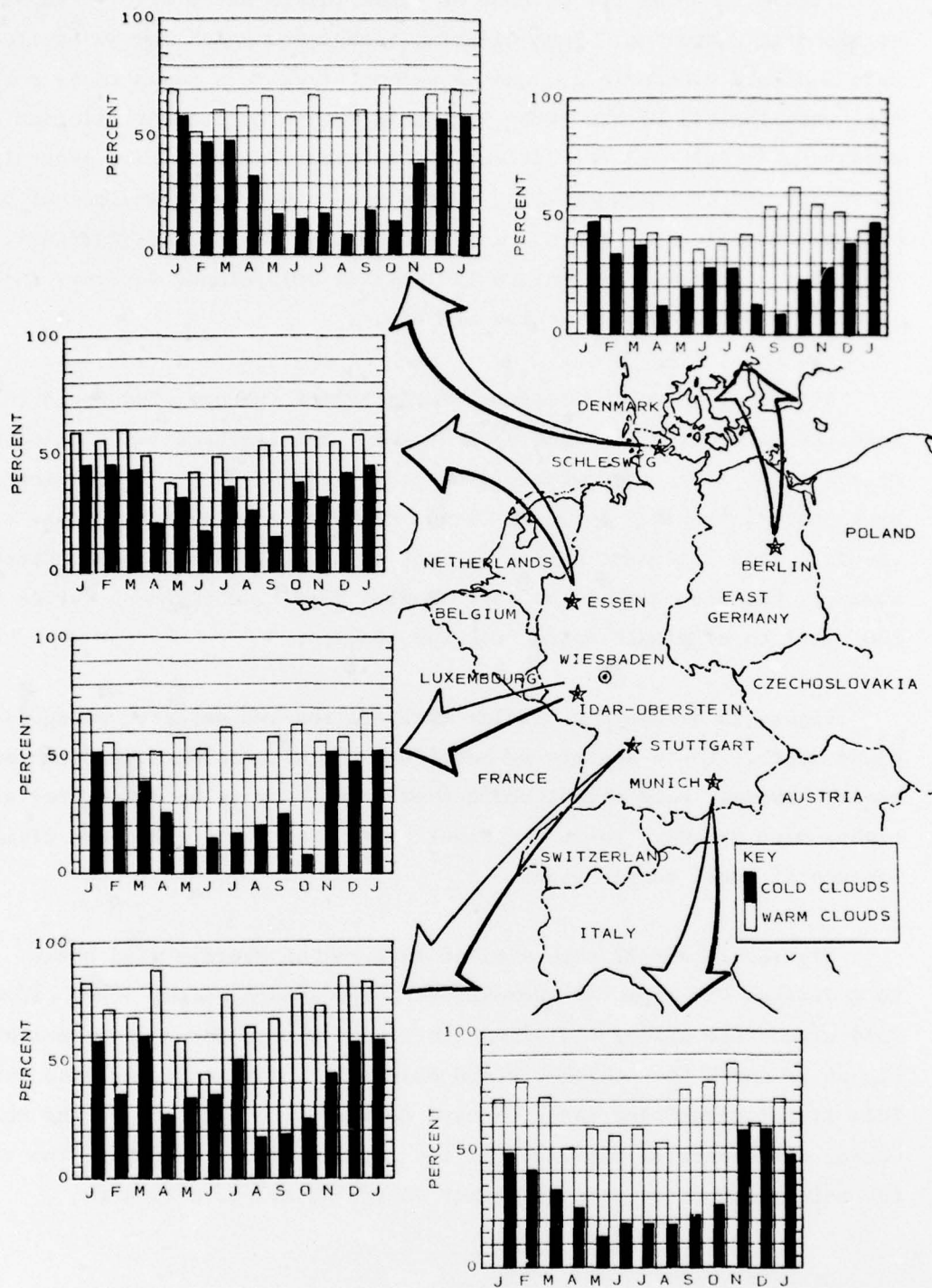
Figure 23. Percent of cloud layers capped by inversions.

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Figure 24. Seasonal variation in wind speed for selected cloud base categories. Average wind speed is plotted. Where plots are interrupted, no data were available.

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Figure 25. Seasonal variation in wind speed for selected cloud depth categories. Comments from Figure 24 apply.

44

Figure 26. Seasonal variation in wind shear for selected cloud base categories. Average wind shear is plotted. Where plots are interrupted, no data were available.
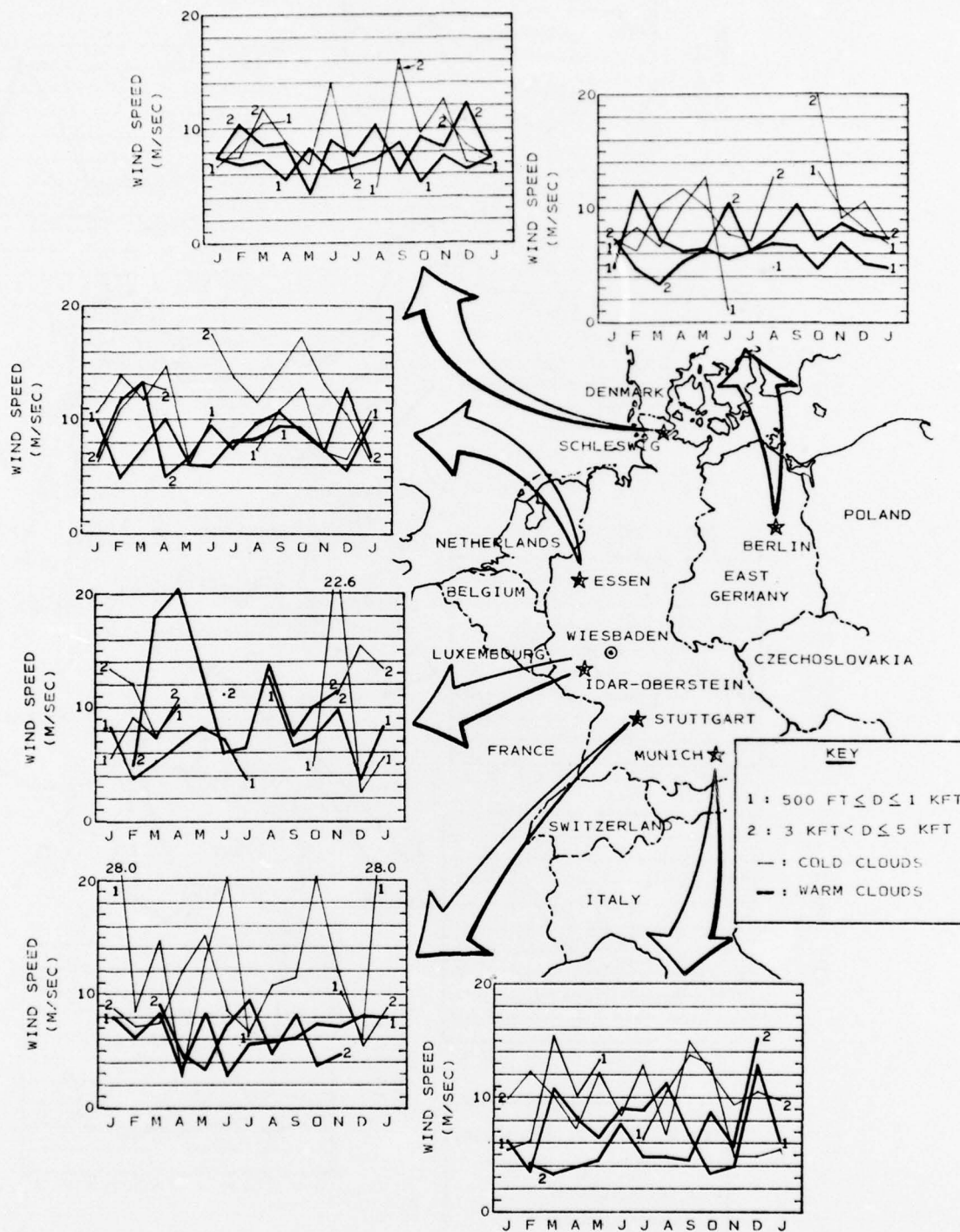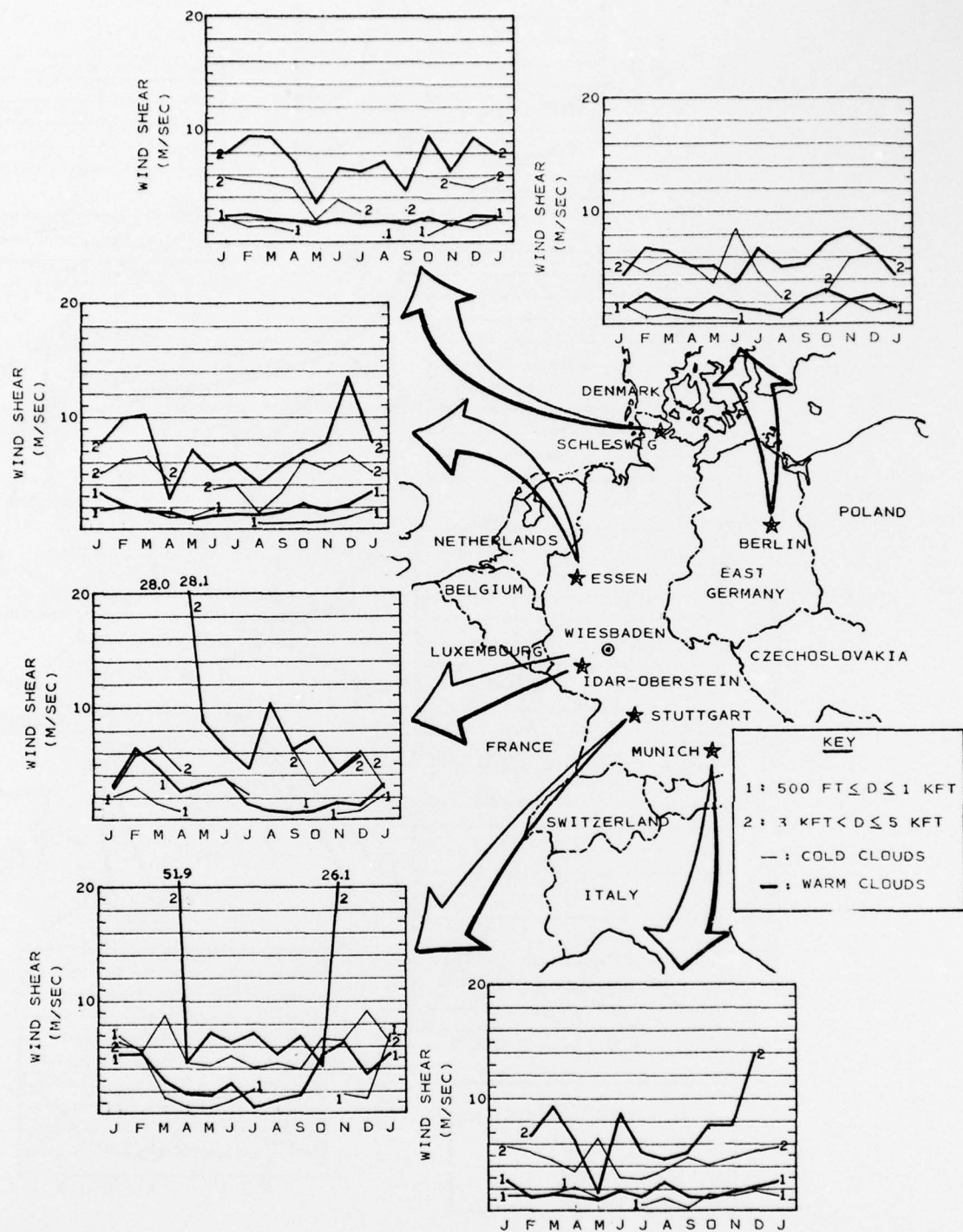
45

Figure 27. Seasonal variation in wind shear for selected cloud depth categories. Comments from Figure 26 apply.

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7.   SUGGESTIONS FOR FURTHER STUDY

7.1 Additional Summarizations

A great deal more useful information is available on the data files
produced by this effort. Parameters are available on the tapes which were
not presented here, such as stability of the cloud layers, depth of inver-
sions, strength of inversions, etc. More detailed analysis of cloud tempera-
ture would be quite useful in developing tactical cold stratus clearing
techniques. Additional analysis of the structure of thermodynamic stability
would be useful in the development of some techniques for clearing warm
stratus. The seemingly endless possibilities for presentation of the data
require a well-planned approach to their presentation.

A broad overview of the general characteristics of stratus clouds was
given here. Development of more detailed presentations should be responsive
to the requirements of specific applications and be tailored to their needs.
We feel that the most useful approach to answering questions of tactical
significance is that of developing scenarios of possible situations. For
instance, we could ask how often could an aircraft at a given altitude be
expected to see the ground. We could then ask how these statistics would
be improved by the application of presently available techniques which can
produce clearings in cold stratus decks less than 800 meters thick. How
much improvement would be realized if all cold stratus could be cleared?
What would happen if an effective technique for clearing warm stratus is
developed, accounting for its probable restrictions? Stratocumulus decks
tend to be more difficult to clear. How important is it to be able to clear
these clouds? The answers to these and similar questions can be obtained
quickly from the data tapes and should aid significantly in the orderly
development of tactically useful stratus clearing techniques.

7.2 Verification Data

There is an unfortunate sparsity of data with which to verify the
accuracy of the method's determination of bases and tops of the cloud layers.
The usefulness of surface data is limited in this regard since it is only

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relevant for the base of the lowest layer and possesses questionable accuracy at the higher altitudes. A program of aircraft observations coincident with rawinsonde observations would provide the most desirable, but probably the most expensive, data for verification. Accurate determinations of cloud base, cloud top, and coverage of the layer would be possible.

Less desirable, but also less expensive, would be the use of modified rawinsonde instruments capable of detecting in-cloud conditions. This could be accomplished by various methods of sensing visibility or liquid water content. Cloud base and top information would be made available, but not coverage. Coverage could also be obtained if the instrument was equipped with a recoverable camera. However, the recovery process could prove a formidable task.

It is quite important that the analysis method be verified with appropriate data so that increased confidence may be placed in the results. The verification using surface data is useful, but it is limited in many critical aspects.

7.3 Improvement of the Analysis Method

Given the limitations of the data available for verification, we felt it would be unproductive to refine the analysis method by inclusion of more sophisticated concepts. When better data are available, it would be appropriate and advisable to refine the analysis technique. Characteristics of the temperature profile should be included: 1) the wet-bulb effect of a wetted thermister emerging into clear air often procedures false super-adiabatic lapse rates just above cloud top, and 2) the prevalence of inversions associated with cloud top may serve to better define the top. Instrument lags should be considered. The possible effects of insolation and the entire history of the ascent should be included in the analysis.

A technique including these factors would be challenging to develop and complicated to automate. Given appropriate verification data, however, it should be possible to produce significant improvements in accuracy and in confidence in the results.

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7.4 Application to Other Regions

We strongly urge that programs to obtain high quality verification data be included in other studies of this kind. Although useful analyses can be performed using only standard surface and upper air observations, we feel the inclusion of good verification data, such as special aircraft observations, would contribute greatly to the accuracy and confidence of the results.

When studying other regions, the analysis method will probably require modification to account for the characteristics of the different kinds of rawinsonde instruments and varying environmental conditions such as the zenith angle of the sun, character of the cloudiness, etc. This study was fortunate to have data from the German instrument which appears to provide a very high quality of humidity data. It unquestionably outperforms the U. S. instruments of the same period.

ACKNOWLEDGMENTS

FORMATS OF THE FILES

A.   SURFACE DATA (Figures A-1 and A-2)

Every observation during the time period that we had both surface and upper air data was used. That is, if we had no 1967 data for an upper air station we did not decode the 1967 surface data, even though we had it. The only exception to this rule was Schleswig, where the decision to discard 1960 through 1962 of the upper air data was made after the decoding of the surface data.

1.   TDF13 (Schleswig, Essen, Munich)

Each logical record of 97 characters is made up of one observation. Included are the station number, the date and time in GMT, the notation "13" to designate the source of the data, the total sky cover in percent, the visibility in miles, an indicator of the source of the cloud data (0 for supplemental data; 1 for first cloud group), a two-digit code, 00-99, for present weather and up to four cloud layers,each one comprised of amount in percent, type, and height in meters AGL.

2.   TDF14 (Berlin, Stuttgart, Wiesbaden)

Each logical record of 97 records is made up of one observation. In- cluded are the station number, the date and time in GMT, the notation "14" to designate the source of the data, the total sky cover in percent, the visibility in miles, eight one-digit codes for present weather and up to four cloud layers, each one comprised of amount in percent, type, and height in meters AGL.

A1

Figure A-1 — Surface data (S4) format

STA	DATE			HR	COVER	VIS (MI)	I N D	PRES WX	CLOUD LAYER 1			CLOUD LAYER 2			CLOUD LAYER 3		
	Y	M	D	(Z)	%				AMT	TYPE	HEIGHT	AMT	TYPE	HEIGHT	AMT	TYPE	HE
x x x x x	x x	x	x	x x	x x	x x x x · x x	x	x x	x x x	x x	x x x x x	x x x	x x	x x x x	x x x	x x	x

	CLOUD LAYER 4		
	AMT	TYPE	HEIGHT
IGHT	x x x	x x	x x x x x

(X, I5, X, I3, F4, F6.2, 3X, I1, 11X, I2, 4(F4, F3, F6))

Figure A-1. Surface data (S4) format - TDF-13. See text for explanation.

Figure A-2 — Surface data (S4) format

STA	DATE			HR	COVER	VIS (MI)		PRESENT WEATHER						CLOUD LAYER 1			CLOUD LAYER 2			CLOUD LAYER 3		
	Y	M	D	(Z)	%									AMT	TYPE	HEIGHT	AMT	TYPE	HEIGHT	AMT	TYPE	HE
x x x x x	x x	x	x	x x	x x	x x x · x x		x	x	x	x	x	x	x x x	x x	x x x x x	x x x	x x	x x x x x	x x x	x x	x

	CLOUD LAYER 4		
	AMT	TYPE	HEIGHT
IGHT	x x x	x x	x x x x x

(X, I5, X, I3, F4, F6.2, X, 8I2, 4(F4, F3, F6))

Figure A-2. Surface data (S4) format - TDF14. See text for explanation.

A2

B.   MASTER FILES (Figure A-3)

The six master files are a result of appending the cloud layers and inversions from the upper air soundings to the corresponding surface data record. The surface temperature in °C (6 characters) from the soundings is inserted between the present weather and the first cloud layer; otherwise it exactly matches the format of the surface data. The six characters of the temperature means that the surface portion of the record now occupies 103 characters.

There are five cloud layers from the sounding, each one occupying 67 characters. Obviously, not every sounding had five cloud layers; where less than five were found the fields in the remaining layers are filled in with -0's. Each layer has the following parameters: pressure at the base in mb, depth of the layer in mb, height of the base in meters AGL, thickness of the layer in meters, temperature at the base of the layer in °C, temperature at the top, minimum temperature within the layer, mean stability of the layer in °C m^{-1}, mean wind direction and velocity (m/sec) between the top and bottom of the layer, scalar wind shear (m/sec) from base to top, and the critical value of relative humidity, in percent, used to define a cloud layer.

The cloud layers are followed by the number of layers actually found, in 2 digits. It can range from 0 to 6; if it is 6 no information is given for the sixth layer.

Following are five inversions, each occupying 39 characters. Isothermal layers were considered to be inversions. Again, if fewer than five inversions were found, the fields in the remaining ones are filled in with -0's. The information for each inversion consists of: pressure at the base in mb, depth of the inversion in mb, height of the base of the inversion in meters, thickness of the inversion in meters, temperature at the base in °C, temperature at the top and mean stability in °C m^{-1}.

A3

The inversions are followed by a two-digit field containing the number of inversions found. It can range from 0 to 6; if it is 6 no information is given for the sixth inversion.

The final entry of the record is the highest level reached by the sounding. This is a seven-digit field. A -0 in this field does not denote missing data; several stations did not enter a height when a sounding terminated above 50 mb.

A4

First Cloud Layer From Sounding

Second Cloud Layer From Sounding

Third Cloud Layer From Sounding

Cloud Layer From Sounding

Layer From Sounding

First Inversion

Second Inversion

Third Inversion

Fourth Inversion

Fifth Inversion

(X, I5, X, 4I2, I3, F4, F6.2, X, 8F2, F6.1, 4(F4, F3, F6), 5(F5, F4, 2F6, 3F6.1, F7.3, F4, F5.1, F4, F5.1, F3), I2, 5(F5, F4, F6, F5, 2F6.1, F7.3), I2, F7)

Figure A-3. Master file format. See text for explanation.

A5